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Autonomous Aircraft Initiative Study

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PREFACE

This report was prepared by G&C Systems, Inc. for PRC Systems Services under contract ATD-89-GNC-1504. The material presented herein represents the views of the author and should not be construed as representing a NASA or PRC position or endorsement. The author wishes to thank Eugene Duke, Denis Bessette, Dwain Deets, Kenneth Szalai and Kevin Petersen of NASA Ames Dryden, and William McCain and Randal Brumbaugh of PRC Systems Services for their support and encouragement for this work.

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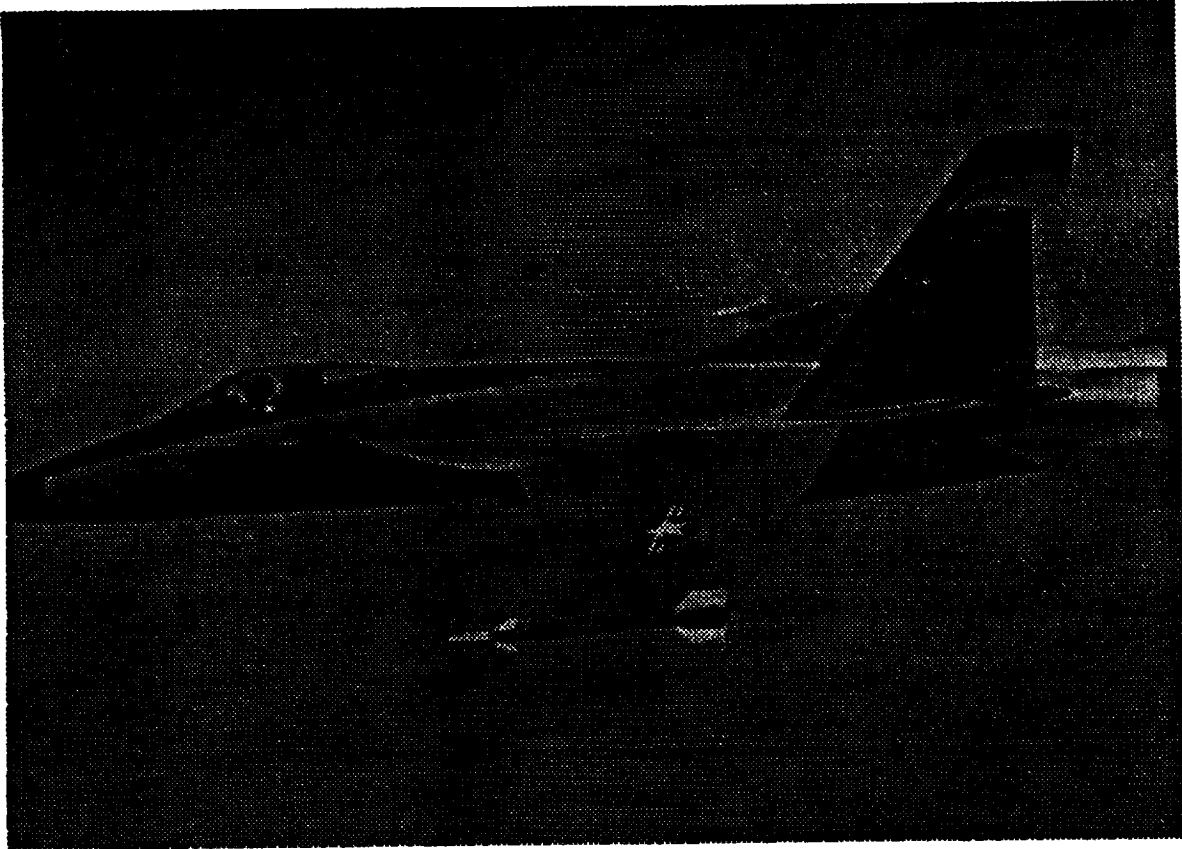
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NOMENCLATURE

A/C	Aircraft
Ada	Department of Defense All Purpose Higher Order Language
AFTI	Advanced Fighter Technology Integrator
AGL	Above Ground Level
AI	Artificial Intelligence
ARTC	Air Route Traffic Control
ATMS	Automated Flight Test Management System
ATR	Air Transport Rack
AWACS	Airborne Warning and Control System
BVR	Beyond Visual Range
C	The C Higher Order Language
CAS	Close Air Support
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
ES	Expert System
FAA	Federal Aviation Agency
FEBA	Forward Edge of the Battle Area
FLIR	Forward Looking Infrared
G	Acceleration equal to gravity
GPS	Global Positioning System
G&C	Guidance and Control
HAARP	High Altitude Atmospheric Reconnaissance Platform
HiMAT	Highly Maneuverable Aircraft Technology
IAAS	Intelligent Air Attack System
ICAAS	Integrated Control and Avionics for Air Superiority
ILS	Instrument Landing System
InMASS	Internetted Multiple Aircraft Surface Strike
I/O	Input/Output

INS	Inertial Navigation System
IRAD	Internal Research and Development
IRMA	Internetted Robotic and Manned Aircraft System
ITAC	Integrated Tactical Aircraft Control
JTIDS	Joint Tactical Information Data System
K	Thousand
LISP	List Processing Language
M	Million
MMH/FH	Maintenance Man Hours per Flight Hour
NAVAID	Navigation Aid
NIH	National Institute of Health
NSF	National Science Foundation
NWC	Naval Weapons Center (China Lake)
RADAR	Radio Detection and Ranging
RAV	Remotely Augmented Vehicle
R&D	Research and Development
RPV	Remotely Piloted Vehicle
SAR	Search and Rescue
SBIR	Small Business Innovative Research Program
TCA	Terminal Control Area
TFM	Tactical Flight Management
UAV	Unmanned Airborne Vehicle
UHF	Ultra High Frequency
US	United States
V&V	Verification and Validation
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
wets	wetstones
WRDC	Wright Research and Development Center



1.0 SUMMARY

This report describes the results of a consulting effort to aid NASA Ames-Dryden in defining a new initiative in aircraft automation. The initiative described herein is a multi-year, multi-center technology development and flight demonstration program. The initiative features the further development of technologies in aircraft automation already being pursued at multiple NASA centers and Department of Defense (DoD) research & development (R&D) facilities. In the proposed initiative, these technology developments are focused on applications to tactical military air warfare involving internettted manned and intelligent unmanned aircraft. Civil "spin-off" applications are also addressed. In defining the initiative, we have attempted to identify the technology areas which require additional development to allow flight demonstrations to be performed. The proposed initiative involves the development of technologies in intelligent systems, guidance, control, software development, airborne computing, navigation, communications, sensors, unmanned vehicles and air traffic control. It involves the integration and implementation of these technologies to the extent necessary to conduct selected and incremental flight demonstrations.

This initiative requires the active participation of three NASA facilities and centers: NASA Ames-Moffett, NASA Ames-Dryden and NASA Langley. A three phase program is described herein. In Phase I each individual center or facility is envisioned as having responsibilities for the development of assigned technologies in their related areas of expertise. In phase II these technologies are integrated in an assigned lead center/facility. In phase III flight demonstrations are conducted at NASA Ames-Dryden. Only selected technology developments sponsored under this initiative are envisioned to go to flight demonstration. Others will be demonstrated in simulation only and still others may not be demonstrated. Multiple phase II and phase III efforts are envisioned to be conducted during the course of the program.

An advocacy plan is presented herein for the solicitation of support for the initiative from DoD R&D facilities, DARPA, and Systems Commands. The central feature of this plan is the formation of a NASA sponsored review panel. We envision this panel as having strong input into the detailed definition of the technology developments to be pursued, in the scenario descriptions required to support the technology developments and in the content of the flight demonstrations. We envision this panel to be active throughout the life of the initiative. We envision this panel to be composed of prominent researchers and developers in the government, and the aerospace industry. We propose that representative operators from the Air Force and Navy, and representatives from appropriate civil agencies also be included on the panel.

The program plan included herein is complete to a high level of detail only. Further work is required over an extended period of time with the involvement of the review panel discussed above in order to develop the program plan.

2.0 INTRODUCTION

The NASA Ames-Dryden Flight Research Facility has participated in the development of automation technology as it relates to aircraft for a number of years. They participated in the development of fly-by-wire flight control, digital flight control and digital engine control. They developed the Remotely Augmented Vehicle (RAV) facility and used it to flight demonstrate a number of advanced concepts in digital control, adaptive control, control augmentation, and flight software verification and validation technology. They expanded the RAV facility to include the capability to support remotely piloted vehicles and supported flight demonstrations of a highly maneuverable advanced technology unmanned vehicle (HiMAT), an F-15 spin demonstration reduced scale unmanned vehicle and a low volatile fuel demonstration using an unmanned civil aircraft. Over the years they have been on the leading edge of developing and flight demonstrating advanced technologies in aircraft automation.

In recent years advances in digital technology and airborne computing have resulted in the development of highly integrated and automated systems airplanes. In addition, advances in artificial intelligence technology has allowed designers to build a high degree of intelligence into

autonomous systems. Advances in these areas has opened the possibility of developing smart multi-vehicle systems that share information between component vehicles to create a highly accurate “world model” coupled with a proactive capability that far surpasses any previous capability. A broad range of applications are envisioned for multi-aircraft systems involving manned command airplanes and autonomous unmanned flight vehicles. The United States Air Force is considering a program to develop an Integrated Tactical Aircraft Control Concept (ITAC). The concept involves the employment of internetted manned and unmanned flight vehicles to perform tactical aircraft missions. In addition, potential spin-off applications are envisioned in civil aviation.

In order to maintain NASA’s traditional role in the development of advanced automation technologies, it is necessary to structure a new initiative. This initiative must reflect the new trends in automation, the interests of the end user agencies, and the obvious advantages available from further developing and integrating the new technologies in intelligent systems, autonomous vehicle systems, internetting and airborne computing. This report describes this new initiative to an advocacy level of detail.

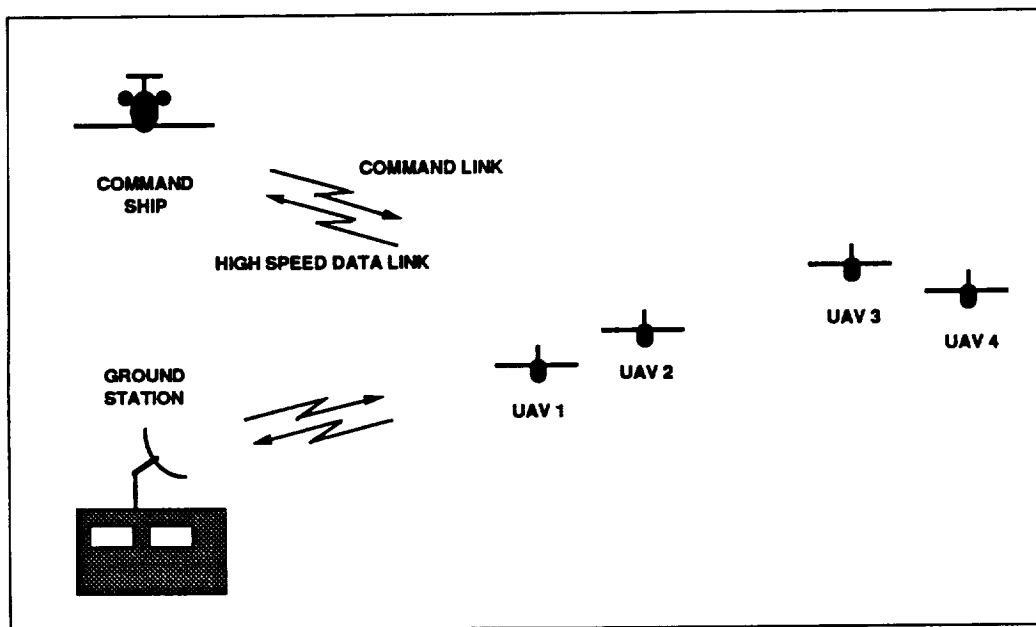


Figure 1 IRMA Concept Definition

3.0 CONCEPT DEFINITION

A broad range of applications are envisioned for multi-aircraft systems involving both manned command airplanes, manned command ground facilities and unmanned robotic airplanes. These systems feature small numbers of manned command airplanes or ground facilities communicating via high speed data link with larger numbers of unmanned robotic airplanes. The

communication involved consists of a low bandwidth command link from the manned to the unmanned vehicles and a high bandwidth data link in the reverse direction. The high bandwidth data link has become known in tactical military world as "internetting". Internetting is defined as the sharing of avionic and sensor information available on each aircraft's avionics bus such that all of the internetted aircraft can be considered as one system. In the context of the manned command aircraft/unmanned robotic aircraft systems concept addressed herein, internetting involves the transfer of information from the robotic aircraft to the manned command airplane or ground facility. In return the command aircraft or ground facility issues mission level commands to the robotic aircraft under its supervision. We refer to the concept hereafter as IRMA (Internetted Robotic & Manned Aircraft System). The concept is shown pictorially in Figure 1 above.

The robotic aircraft in IRMA are capable of operating in close proximity to command aircraft and with each other in a cooperative fashion. They contain enough artificial intelligence to correctly interpret mission level commands and execute them, make correct lower level decisions and execute them, filter own sensor information and pass critical information to the command aircraft, correctly assess when decisions are required and what decisions need to be deferred to the command ship. Mission level commands are defined as those types of commands which would normally be communicated via voice (UHF radio) between flight leaders or commanders in lead/coordinating aircraft or between ground stations and aircraft.

Advances in intelligent systems, robotics, computer processing, automation, sensors, navigation, air traffic control, displays and communications now open the possibility for building and deploying smart multi-vehicle systems that share information between aircraft and employ unmanned aircraft as a means of significantly increasing a payoff to cost ratio. The technology components are sufficiently developed to build and flight demonstrate IRMA systems for a number of applications. These include both military tactical air and civil applications. Military applications include both tactical and strategic missions. Tactical air-to-ground missions include interdiction, strike, and reconnaissance. Tactical air-to-air missions include fighter sweep, intercept, combat air patrol, and counter air. The strategic mission is one of presenting decoys to the enemy during a strategic strike. Civil applications include air-to-air and air-to-ground drug interdiction missions, border surveillance missions, search and rescue missions, forest fire fighting missions, high altitude atmospheric sampling and commercial logging. Figure 2 on the next page presents a pictorial of the military applications and civil spin-off applications.

3.1 The Rationale Behind the Concept

The primary purpose of employing IRMA systems is to reduce the risk of loss of human life through the use of robotic vehicles to perform the more dangerous tasks in a military or civil mission.

A secondary, but important purpose, is to realize a significant increase in operational capability per dollar spent over traditional/conventional methods of operation. This increase is possible because IRMA has the following significant advantages over conventional operations:

- 1) significantly lower numbers of airborne human flight crew are directly involved in IRMA operations compared to conventional operations;
- 2) the costs associated with procuring, operating and maintaining UAV aircraft and associated equipments are lower than manned aircraft;
- 3) UAV's can be designed for higher performance and lower observability than manned aircraft.

In the following sections, we present the arguments for developing and deploying IRMA systems more fully.

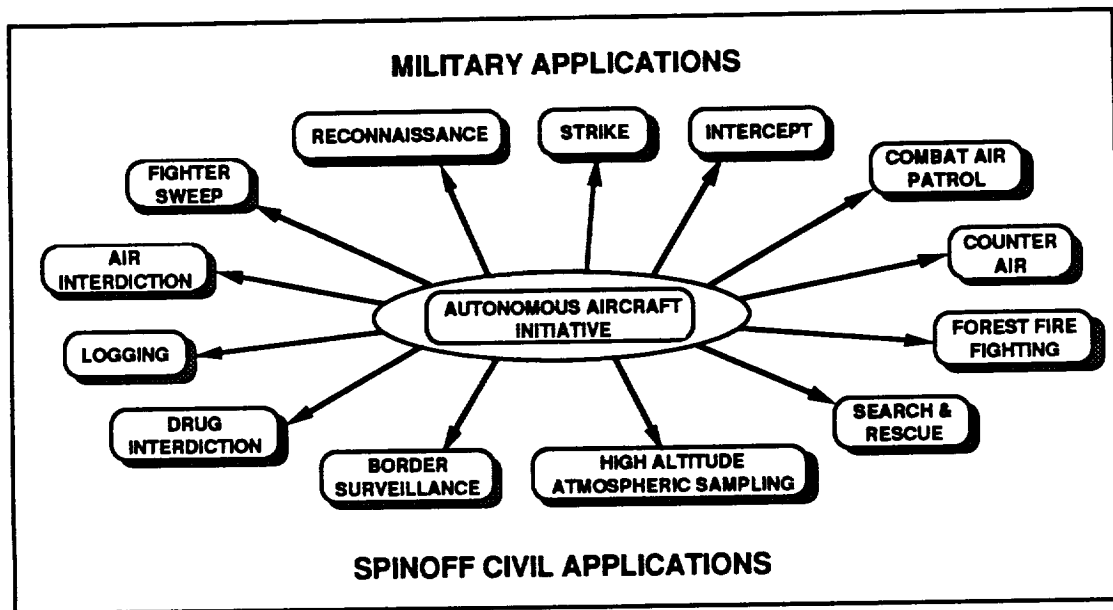


Figure 2 Military Applications and Civil Spin-off Applications of IRMA

3.1.1 HIGH RISK MISSIONS

The primary objective of employing IRMA systems is to reduce the risk of loss of human life through the use of UAVs to perform the more dangerous tasks in a military or civil mission. The IRMA concept allows human flight crews in manned aircraft or ground stations to exercise

supervisory control over UAVs. The UAVs generally perform the "close in" portion of a civil or military mission while the human operator maintains a "stand off" distance out of harm's way. The concept applies equally to tactical combat missions and forest fire fighting as examples. The human operator is removed to the point where more than simple remote control of the UAV is required to perform the mission: that is, the UAV must possess a certain level of machine intelligence to allow it to be able to respond correctly to high level commands. We coin the term "continuous standoff" to describe this method of operation. The essence of this method is that human supervisors are being used on a continuous basis to observe a situation from a standoff distance and to control (at a high level) UAVs to accomplish a mission.

A second method of operation is "assign and leave". The concept involves the use of human operators to observe a situation, assign UAVs to accomplish a mission and leave the vicinity of the operation or at least curtail observation and further control. The method has very useful tactical military applications as well as civil applications. For example, manned military tactical aircraft can generally survive in a high threat environment for a short period of time if they achieve surprise. That period of time could be enough to observe a tactical situation, make mission/strike assignments to UAVs and depart the area leaving the UAVs to conclude the mission (attack assigned targets, etc.) and assume the risk associated with the enemy's reacting defenses. This method is also appropriate for search and rescue operations, and reconnaissance missions.

Whatever method of operation is used, it is clear that there is considerable potential payoff associated with using smart UAV's to perform high risk civil and military missions.

3.1.2 FLIGHT CREW TRAINING, SUPPORT, RETENTION AND REPLACEMENT

Although the primary reason for employing unmanned systems is to reduce losses of human life by using unmanned vehicles to perform high risk segments of missions, there are other good reasons for employing unmanned systems as well. In this section, we address the problems and costs associated with training, supporting and retaining flight crews in both military and civil aircraft.

The problems of flight crew training, support and retention are more serious in the military than in civil flying. The average military flight crew member requires eighteen months to earn his Air Force or Navy wings and spends five years on flying duty before resigning from the service. A small percentage of flying officers make the service their career. During the time the individual is in the service, he or she must be supported with medical facilities, housing, recreation facilities (golf courses, gymnasiums, officer's clubs), training and education facilities, commissary facilities, exchange facilities, banking facilities, credit unions, supervision, religious support, legal support, transportation support, even a self-contained military welfare system (the Navy Relief Society, for example). Sprawling bases cater to their needs. Maintaining trained flight crews is an expensive proposition.

The Air Force and Navy have experienced decades of frustration with low flight crew retention rates. For years the airline industry has been the beneficiary of military pilot training. The typical military pilot leaves the service after his obligated service to join the airlines. The Vietnam war taxed this country's supply of tactical pilots. Pilot training command inputs had to be increased significantly in both the Air Force and Navy during the period of the war, and the Navy had to initiate a very expensive bonus program to get tactical pilots to remain in the service beyond their initial five year obligation. Bonuses of \$50,000 and more were not uncommon to persuade tactical Navy pilots to stay in the service for an additional tour beyond their obligation during the war.

Human resources are often more difficult to train and support than equipment is to build and maintain. In addition, it is more expensive to keep humans in uniform than to build equipment to replace them where possible. In a society which has to operate superior equipment to maintain an edge over a potential foe with a larger population base and a larger defense budget to draw from, finding ways to employ our technical edge to advantage is a must.

Figure 3 presents a comparison of life cycle costs for two "configurations" which provide similar operational capability. We define configuration A as consisting of one manned aircraft and supporting flight crew (2), plus three UAV's. Configuration B consists of four manned aircraft and supporting flight crew (8). We compare procurement, and training costs, plus support, and operating costs over a five year period.

Figure 3 Manned Aircraft vs. UAV 5 Year Cost Comparison

Expense Item	Time	Configuration A	Configuration B
FLIGHT TRAINING	1 1/2 years	\$400 K	\$1,600 K
AMORTIZED AIRCRAFT PROCUREMENT	1 1/2 years	\$12,500 K	\$20,000 K
FLIGHT CREW SUPPORT	5 years	\$1,500 K	\$6,000 K
AIRCRAFT OPERATING EXPENSES	3 1/2 years		
Maintenance Support		\$1,400 K	\$1,700 K
Fuel		\$2,300 K	\$3,100 K
TOTAL AMORTIZED EXPENSES		\$18,100 K	\$32,400 K

The ground rules for the comparison are as follows:

1. Flight training requires 18 months to complete. No amortization is calculated as average flight crew time of service is considered to be 5 years.
2. Aircraft procurements are \$20,000 K per manned aircraft; \$10,000 K per UAV. Procurements are amortized over 20 years.

3. Flight crew's average salaries are \$50 K per year. Total flight crew support produces a multiplier of 3.0 on salary.
4. Manned aircraft require 10 maintenance man-hours per flight hour to support. UAVs require 8 maintenance man-hours per flight hour to support.
5. All aircraft fly 200 hours per year.
6. Support (maintenance) crew average salaries are \$40 K per year with a multiplier of 3.0.
7. Fuel costs \$1 per gallon.
8. Average fuel burned for manned aircraft is 7,500 lbs/hr; for a UAV is 5,000 lbs/hr.

The figures, comparisons and assumptions are arguable, however, they do provide some insight into the very high costs associated with training and supporting human flight crew as opposed to designing, procuring and maintaining robotic flying machines.

3.1.3 FLIGHT VEHICLE PROCUREMENT, OPERATION, RELIABILITY AND MAINTAINABILITY

UAVs should cost less per copy than manned aircraft with equivalent capability because they do not have to be man rated. They do not require a cockpit environment, on-board displays, a pressurization system, canopies, ejection seats, and a host of other systems required in manned aircraft. The lack of these systems in UAVs means that fewer ground personnel and less maintenance support are required. Maintenance man hours per flight hour, a standard parameter used for measuring the operational effectiveness of military aircraft, should be less for UAVs.

3.1.4 FLIGHT VEHICLE DESIGN, PERFORMANCE AND OBSERVABILITY

The absence of human flight crew presents designers with the potential to design significant performance improvements into UAVs over their manned counterparts. Performance improvements are possible in nearly all military and civil applications, but the application which has the highest potential is the tactical fighter. An automated wingman would have a tremendous advantage over a manned fighter from a performance viewpoint. Unhindered by the load factor limitations of human crews and the weight and volume of cockpit environmental equipment necessary to support human crews, designers of unmanned fighter aircraft could design high "G" aircraft capable of very high rates-of-turn at high speeds. Fighters must turn at relatively slow

speeds (corner velocity) to achieve maximum rates-of-turn. Corner velocity is higher for higher "G" aircraft with the same lift to drag ratio and wing loading. The problem is depicted in Figure 4 below. The problem inhibits turning performance on many present day manned production fighters with high thrust-to-weight ratios. Both instantaneous and sustained turning performance are key performance parameters which contribute to a fighter's air-to-air combat capabilities.

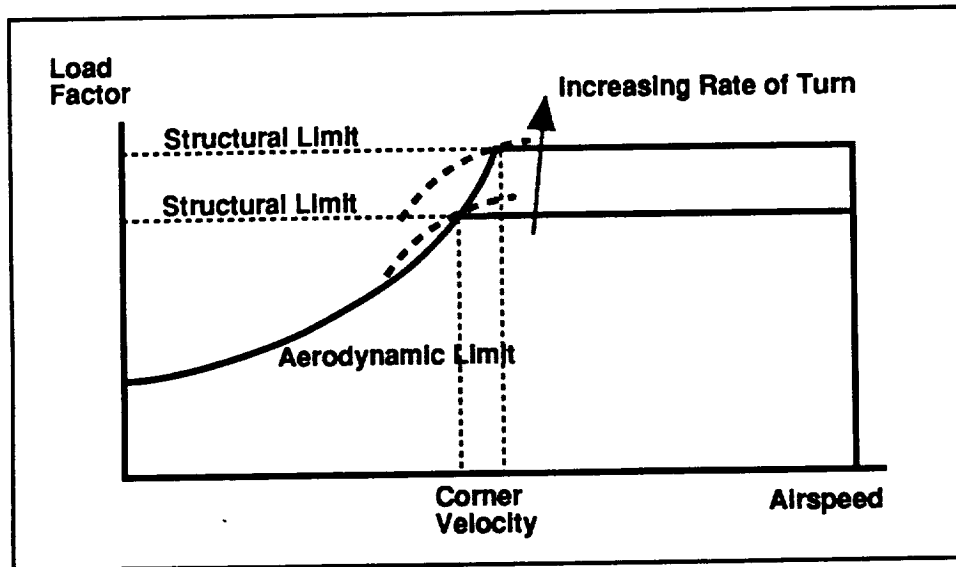


Figure 4 Turning Performance Limitations - Typical Fighter

A second performance advantage which could be built into unmanned aircraft is the ability to pull positive or negative load factor with equal preference. Thus, a 180 degree roll reversal so often performed in air combat would be unnecessary for the unmanned fighter: instead of rolling 180 degrees to perform a reversal, the fighter could simply pull "G" in the opposite direction thus allowing it a tremendous advantage over a manned fighter. In a scissors maneuver (which one-on-one air combat often deteriorates to) roll reversals are performed by both combatants every few seconds. A roll reversal is a 180 degree change in roll attitude required to reverse the direction in which load factor is be applied. During a roll reversal the fighter pilot must relax the "G" load because fighters are generally restricted from pulling rolling "G"s and the lift vector is not pointed in the desired direction anyway. The difference in maximum roll rate between the F-4 (450 degrees per second at corner velocity) and the MIG-21 (100 degrees per second) lead to the development of a defensive fighter tactic used by F-4 pilots which called for a ROLL AWAY from an attacking MIG: a tactic which would normally be considered suicide in fighter circles. While the MIG rolls to match bank angle after a roll away, the F-4 pulls "G". When the MIG finally matches bank angle, the F-4 performs a roll reversal. Again, the F-4 pulls

“G” while the MIG rolls, etc. The result is a continuous build-up of angle-off-the-tail until a defensive reversal is accomplished. The unmanned fighter would have in essence an infinite roll rate capability in a reversal situation.

Observability is another performance parameter which should be reduced for UAV designs. Observability refers to the degree to which a vehicle is detectable by sensors operating in various bandwidths. Designers have more design flexibility with UAVs than manned aircraft. This flexibility allows more freedom in vehicle shape design. In addition UAV designs are likely to be smaller due to the fact that cockpits and other equipments required to support flight crews are not required.

3.2 The Proposed NASA Program

The proposed NASA program involves:

1. conducting research in the technologies required to support this concept for both military and civil applications,
2. developing research prototype IRMA systems and/or components of these systems which can be combined with existing equipments to build demonstratable prototypes, and
3. conducting the flight demonstrations of these prototypes.

The Dryden Flight Research Facility of the NASA Ames Research Center is envisioned as the lead facility for this program. NASA Langley and NASA Ames-Moffett are envisioned as having major supporting roles.

4.0 APPLICATIONS

IRMA has military tactical air and civil applications. Military applications include tactical and strategic missions. Tactical air-to-ground missions include interdiction, strike and reconnaissance. Tactical air-to-air missions include fighter sweep, intercept, combat air patrol, and counter air. The strategic mission is one of presenting unmanned decoys to the enemy in a strategic strike. Civil spin-off applications include air-to-air and air-to-ground drug interdiction missions, border surveillance missions, search and rescue missions (SAR), forest fire fighting missions, commercial logging and high altitude atmospheric sampling. These applications are shown in Figure 5 below and are discussed in detail in the following sections.

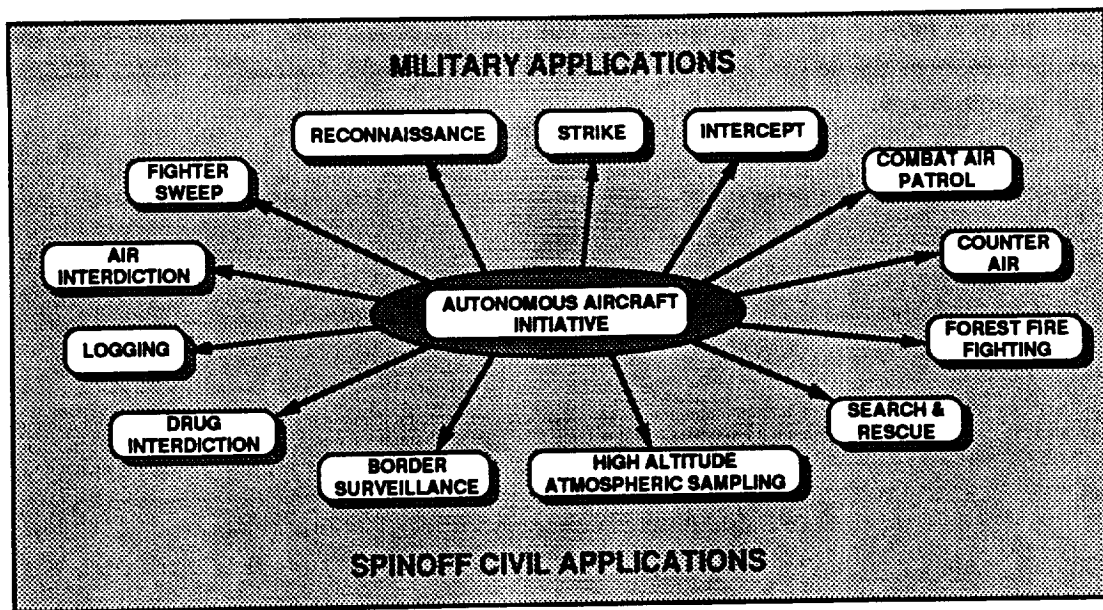


Figure 5 Military Applications and Civil Spin-off Applications of IRMA

4.1 Military Applications

Military applications are discussed in detail in the paragraphs that follow. Applications in tactical aircraft employment are discussed followed by strategic applications.

4.1.1 STRIKE

Strike is the mission of attacking preflight assigned, fixed or semi-fixed targets. UAVs provide two major advantages when used in strike formations with manned aircraft. First, they allow the manned aircraft to achieve standoff in the target area while the UAVs perform the close in, high risk weapons delivery. Second, they multiply a strike force's weapons load carrying capacity and it's sensor ranges without increasing the numbers of human flight crew in the force. A tactical strike group augmented with highly intelligent unmanned wingman (three unmanned aircraft with every manned division leader, for example) could achieve a factor of three improvement in payload per fight crew exposed.

The Wright Research and Development Center's (WRDC) Integrated Tactical Aircraft Control (ITAC) program is dedicated to the development of internetted aircraft technology for tactical missions. The primary scenario is a strike mission. WRDC envisions a strike as being performed by a strike group composed of several UAVs controlled in some high level sense by a manned lead aircraft which is observing the strike from a distance. The idea is to reduce the

risk to the manned vehicle by using standoff. The manned commander continuously or near continuously observes the battlefield: an example of "continuous standoff". The concept is shown in Figure 6 below.

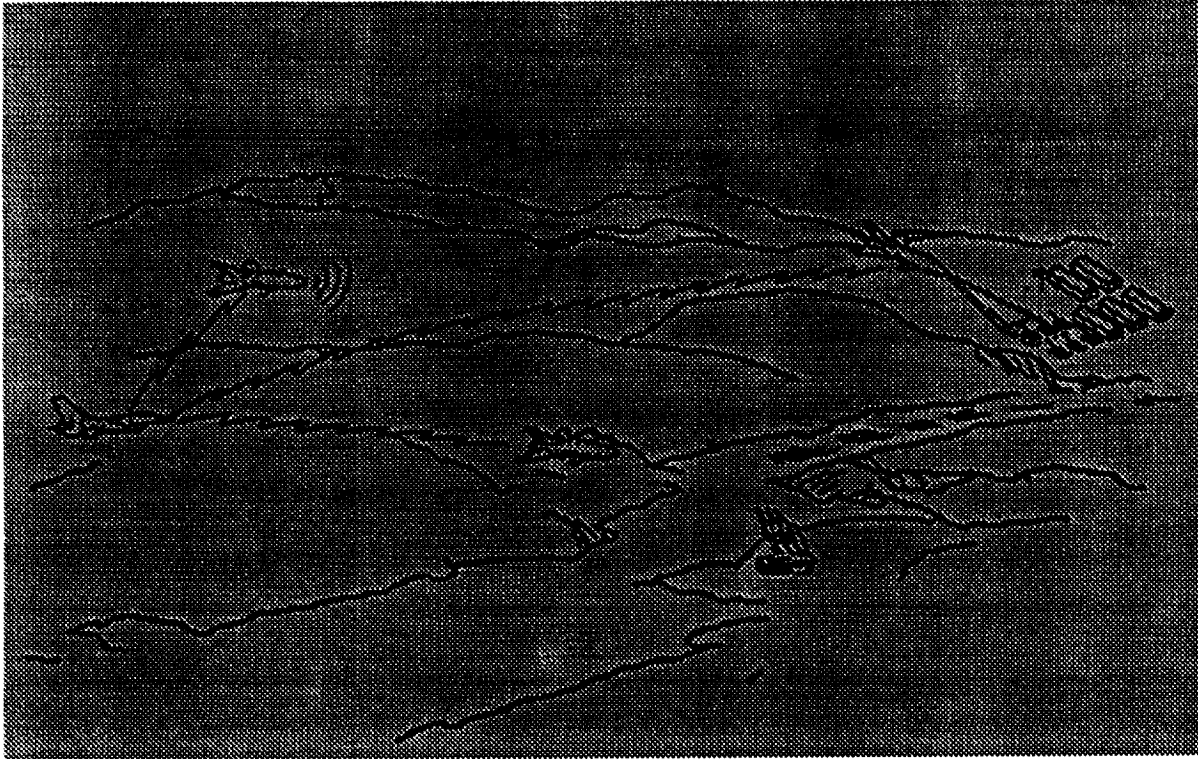


Figure 6 ITAC Strike Scenario

For the concept to work, the standoff must provide protection to the manned aircraft even after the enemy on the ground has recovered from any initial surprise achieved by the attacking strike group; that is, even after the enemy has brought his air defenses to bear. This is true because inherent in the concept is the idea that the manned leader observes the strike and continuously adjusts the UAVs attack orders to the situation. Achieving the necessary standoff also assumes that the strike group knows where all the threatening air defenses are located. A missile squad of soldiers mounting STINGER type missiles stationed undetected under the air space which the manned leader has planned to use to observe the strike from a distance would destroy the standoff concept and likely ruin the leader's day. Still, this is the primary scenario of ITAC, and it has considerable merit.

In addition, the internetting concept allows the strike group to extend its situation awareness capabilities through sensor extensions and reconfigurations. In essence, the internal avionics bus of each internetted aircraft is extended to include the entire strike group. From an

avionics viewpoint, the entire strike formation is one system. A division leader can view on his RADAR scope the return detected by a RADAR receiver in an aircraft on the other side of the formation. A pilot observing an attack on another aircraft by an enemy using a heat seeking missile can deploy flares on the other aircraft or command it to evade via data link. The system is reconfigurable. An avionics or sensor equipment failure on one aircraft can be compensated by "substituting" equipment (through the data link) from another aircraft. The system can be physically expanded, shrunk or reshaped any number of ways by repositioning component aircraft in the formation. The concept is depicted in Figure 7.

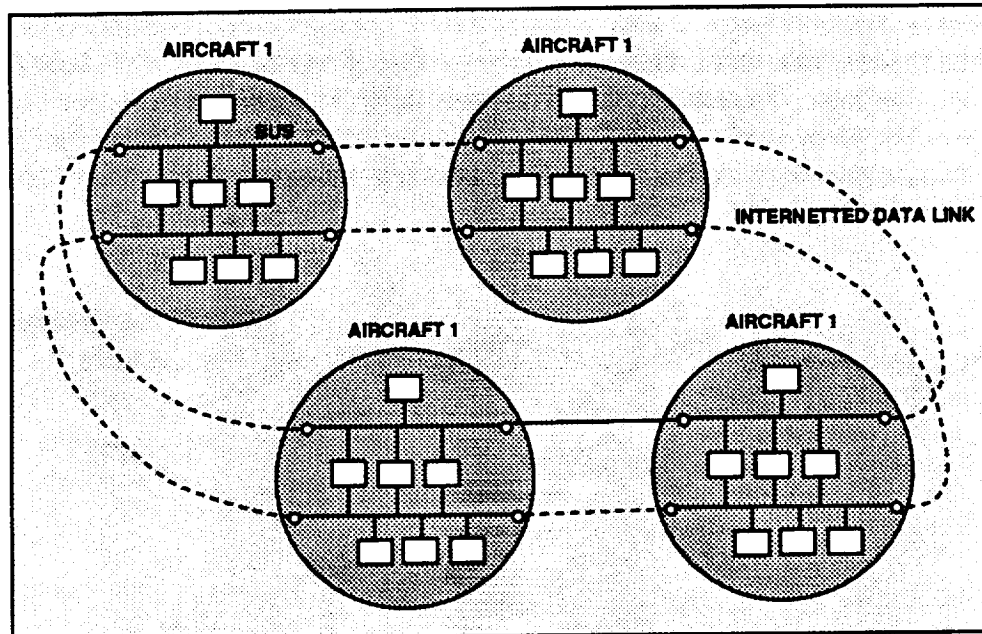


Figure 7 Internetted Avionics Extensions Through IRMA

4.1.2 INTERDICTION

Interdiction is the mission of interrupting an enemy's advance, his supply lines, his reinforcement or his path of retreat. To interdict in the military sense is to forbid with force. In the tactical air warfare world this usually means flying a section (2) or division (4) of aircraft over either a Forward Edge of the Battle Area (FEBA) or behind enemy lines and attacking targets of opportunity. The targets might include supply or reinforcement columns, advance columns, assault columns or retreating columns. Generally, more than one target is attacked on an interdiction mission: the interdiction airplanes roam an assigned area or follow an assigned route looking for targets until they exhaust their attack weapons or reach a fuel bingo state (sufficient fuel remaining to return home). Interdiction targets are usually moving targets whose positions often cannot be predicted prior to the mission.

The mission is in the high risk category against ground forces with good air defense weapons even if all enemy air has been eliminated with fighter sweeps. It is necessary for the interdiction aircraft to fly low enough to see, identify and then attack moving enemy ground forces. Thus, interdiction aircraft often fly within the kill envelope of lower caliber, high rate-of-fire antiaircraft guns, shoulder mounted heat seeking missiles and a variety of smaller caliber weapons used by ground troops. Exposure times are high and surprise is hard to achieve.

In recent years the emphasis in interdiction tactics is to fly small groups of aircraft (two to four) at low level (50 - 200 feet above ground level (AGL)) through target areas. On the first pass, targets are identified and verbally described to other members of the flight who either circle back to attack the target or attack from a trailing position. In either case, the enemy is alerted by the lead aircraft's low pass and is ready to defend itself against the attack when it comes from seconds to minutes later. The attacker's survival probability is significantly reduced due to the warning provided by the lead aircraft. Using a manned aircraft as the target identifier and designator and unmanned aircraft as the trailing attackers solves the high risk problem. The concept is shown in Figure 8.

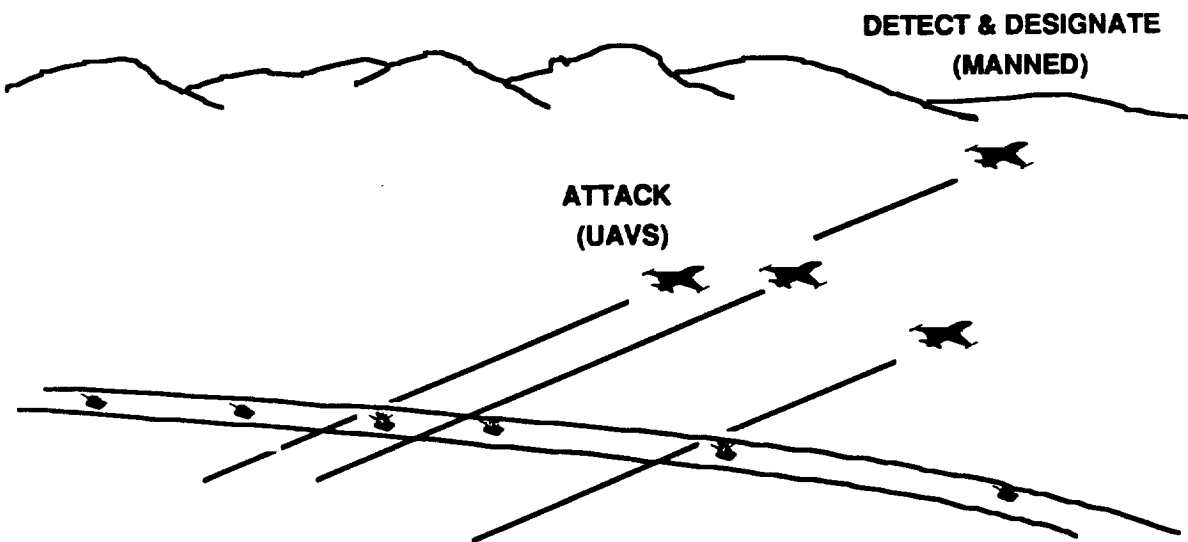


Figure 8 Interdiction Example of IRMA Concept (InMASS)

The concept was first developed at Northrop Corporation and later at SPARTA, Incorporated by Mr. Hershel Melton in a Phase I SBIR sponsored by WRDC. The concept was known as InMASS (Internettted Multiple Aircraft Surface Strike). In this concept, the entire formation operates below 200 feet. The lead (manned) aircraft makes one pass over the target area. He is gone before the enemy can react. Targets are designated and assigned to unmanned trailers by the lead aircraft via high capacity/high speed internetted data link. These highly maneuverable, unmanned attacking aircraft fly two to ten seconds (approximately 1000 to 5000

feet) behind their leader. They use forward firing weapons (cannon), aerodynamically braked general purpose bombs (snake-eye series Mk-82), anti-personnel cluster bombs or specially designed smart weapons to attack their targets. If general purpose bombs are used, the snake-eye series bomb fins are required in low altitude deliveries to slow down the weapon after it is released to keep the fragmentation pattern from the 500 lb Mk-82 warhead from destroying the attacking aircraft. The problem of avoiding weapons fragmentation patterns in low altitude attacks is well known in tactical warfare circles. The problem is depicted in Figure 9 below. The internetted data link is millimeter-wave to limit range, resist detection and provide anti-jamming protection.

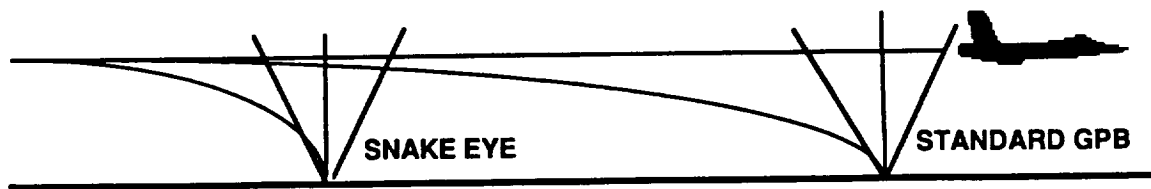


Figure 9 Low Altitude Release With General Purpose Bombs

The advantages of using unmanned aircraft in this mission are enormous. The lead manned aircraft are seldom subjected to high risk because they achieve surprise. The concept employs the “assign and leave” principle of commanding the UAVs as opposed to the “continuous standoff” principle discussed in the Strike mission. The unmanned aircraft must face the enemy’s guns while the manned leader has departed the area before the enemy can react to the surprise associated with the low altitude flyover. The UAVs are better designed to survive against the enemy because the fact that they are unmanned allows high design structural load factors to be built in, thus improving maneuverability significantly. This increased maneuverability translates to improved survivability for the attackers (trailers) on two counts. First, survivability is improved because higher angular accelerations can be presented to enemy tracking weapons. Second, survivability is improved because the trailing aircraft can alter their flight paths to perform an assigned attack faster: thus, the time between target detection, designation and attack can be reduced, i.e. the distance between lead and trailers can be reduced. Short distances between lead and trailers can be tolerated because of the use of high speed internetted data links to transmit target designation and position information as opposed to voice communication.

In this interdiction concept, the attacking aircraft make only one low altitude pass over the interdicted column. The low altitude strike group then proceeds to attack another column and may return to previously attacked columns later in the interdiction mission. Multiple columns are attacked until the formation reaches a bingo fuel state (time to go home) or exhausts its weapons. Several of these formations may be roaming a battle theater simultaneously.

Coordination between groups and track adjustments would be made through JTIDS type communications with a command center. The concept applied on a theater level against an attacking army moving in columns along available transportation corridors is depicted in Figure 10 below.

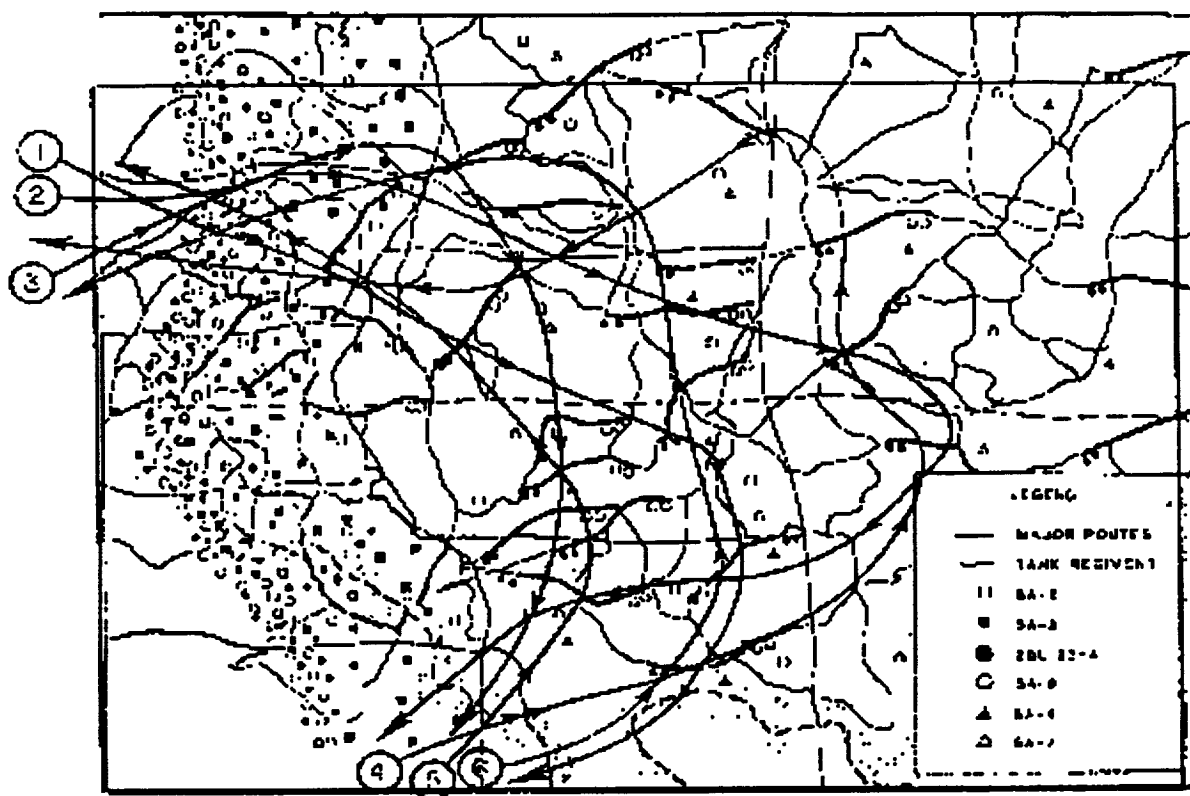


Figure 10 The Interdiction IRMA Concept on the Theater Level (InMASS)

This interdiction IRMA scenario and concept are not being pursued in WRDC's ITAC program.

4.1.3 AIR RECONNAISSANCE

Air reconnaissance is the mission of gathering information by flying aircraft over enemy territory. Generally these missions are flown by single aircraft following preplanned routes. They may be flown at any altitude from very low level to very high level. Aerial photography is the most widely used method of gathering information. The mission is often high risk when flown at low and medium altitudes because of the necessity of flying an undisturbed straight line path when the cameras are running, which is often through a highly defended area. Reconnaissance pilots must often ignore enemy fire to obtain good quality photographs.

Air reconnaissance is now done to a limited extent with UAVs. This mission was the first to be recognized as a natural for unmanned vehicles. Since the mission does not require reconnaissance UAVs to be flown in close proximity to manned aircraft, it was relatively easy to achieve operator acceptance of the concept. In addition, since most missions are flown along preplanned routes, these UAVs do not have to possess a great deal of machine intelligence: no decision actions are required in flight.

Providing a degree of on-board machine intelligence will allow UAVs on reconnaissance missions to display some decision making capabilities. These capabilities would be most appropriately used to alter preplanned flight paths in the presence of detected weather changes particularly in the target area and to deal with other flight anomalies such as equipment failures.

4.1.4 FIGHTER SWEEP

Fighter Sweep is the mission of eliminating enemy air power within a specified volume of airspace. As wingman in a fighter formation, intelligent unmanned aircraft offer an impressive list of potential performance advantages over manned aircraft. These advantages were presented in section 3.1.4. In summary, UAVs can be designed with:

1. Higher thrust-to-weight as a result of the elimination of the cockpit, pressurization, flight instruments, displays and controls;
2. Higher structural load factors and equal positive and negative load factor limits due to the elimination of the need to consider flight crew limitations;
3. Longer range as a design tradeoff with thrust-to-weight due to the elimination of the cockpit, etc.;
4. the potential of using the UAV itself as a weapon in an extreme situation.

The command interface between the automated wingman and the manned lead in a fighter section would be via UHF radio and internettted data link. Voice recognition and natural language understanding, two mainstream AI technologies, would be required on-board the unmanned aircraft to understand the lead pilot's commands. The unmanned aircraft would have to possess enough machine intelligence to interpret and execute the same high level commands that a fighter lead normally gives to his wingman. Wingman responses would be relayed to lead through the internettted data link. These responses could be either displayed on a HUD as symbols or as voice responses in lead's headset. The voice response option requires implementation of another AI technology - speech synthesis. Figure 11 shows a division (4 ship: 1 manned, 3 UAV) executing a 90 degree turn during a fighter sweep mission. The fighter spacing and relative positions are typical of a sweep formation.

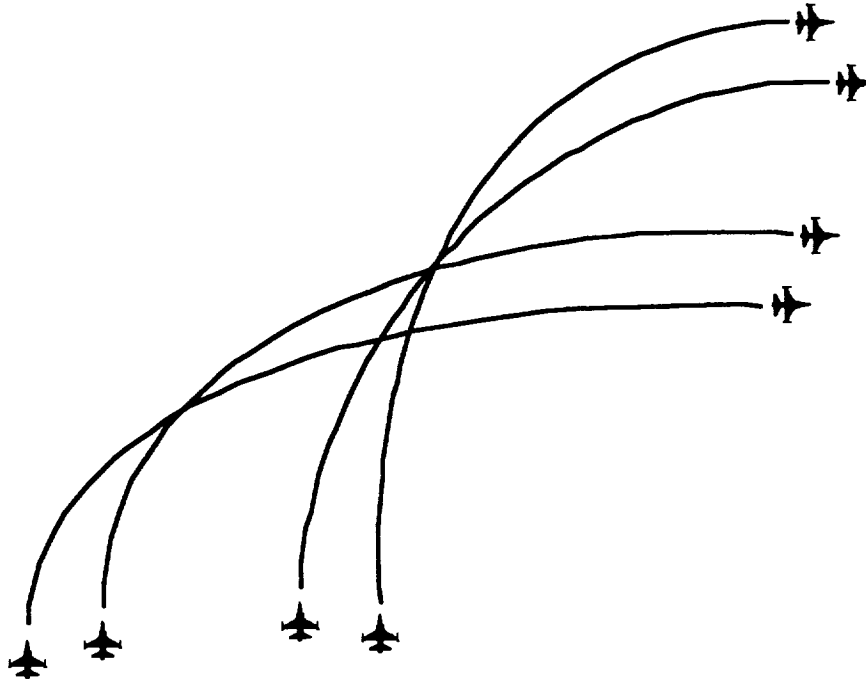


Figure 11 IRMA Fighter Sweep - Division Turn

4.1.5 INTERCEPT

Intercept is the mission of preventing enemy aircraft from penetrating friendly air space through the use of friendly fighter or interceptor aircraft. Unknown aircraft (bogies) are tracked and identified (usually visually). If bogies are classified as unfriendly, friendly air space penetration is prevented by either destroying them, forcing them to land or forcing them to turn away.

The role for unmanned vehicles in this mission is either that of an automated wingman for a manned flight lead or as a totally unmanned flight under the command of a remotely located flight controller. The flight controller might be physically located in a ground facility or in an early warning aircraft. If the unmanned interceptor is an automated wingman under the command of a manned lead aircraft, then the application is similar from a technical requirements point of view to the fighter sweep application described above.

If the mission is performed totally by unmanned aircraft then the level of technology development required to support the concept is increased. In this case the command interface between the unmanned interceptor and the ground or air controller would be via UHF radio and internettted data link. Voice recognition and natural language understanding, two mainstream AI

technologies, would be required on-board the unmanned aircraft to understand the controller's commands. The unmanned aircraft would have to possess enough machine intelligence to interpret and execute the same high level commands that a controller normally gives to an interceptor. Interceptor responses would be relayed to lead through the internettted data link. These responses could be either displayed on the controller's display (usually a RADAR display) as symbols or as voice responses in the controller's headset. The voice response option requires implementation of speech synthesis.

Another technology which requires significant development to implement the totally unmanned intercept mission is image understanding (also known as computer vision). A significant aspect of the intercept mission is identification. An unidentified bogey must be classified. This is normally done visually by the interceptor pilot after the intercept is completed. The technology required to do this autonomously involves high resolution video cameras and sophisticated image understanding. The image understanding software does not have to be hosted on the interceptor vehicle.

4.1.6 COMBAT AIR PATROL

Combat Air Patrol is the mission of patrolling the boundaries of friendly airspace for the purpose of providing readily available support for another mission such as intercept, fighter sweep or counter air. The application of unmanned aircraft for this mission is as either automated wingmen or fully unmanned patrols under the command of a remotely located controller. Both of these applications are described in previous sections.

4.1.7 COUNTER AIR

Counter Air is the mission of defending a specific air space against enemy fighter sweeps and strikes. The application of unmanned aircraft for this mission is as either automated wingmen or fully unmanned flights under the command of a remotely located controller. Both of these applications are described in previous sections. The fully unmanned flight under the control of a remotely located controller is probably many years from implementation for this mission because the mission is extremely difficult and demanding from a decision making point of view. This mission is the most demanding of all previously described missions for tactical flight crews. Human presence at the point of attack is necessary, however, the automated wingman concept is implementable.

There is a strong argument for the use of UAVs in counter air from a risk point of view. Counter air requires a very high degree of coordination to prevent friendly counter air aircraft from being shot down by friendly anti-aircraft weapons (artillery or surface-to-air missiles). Zones are normally established over friendly territory. In certain zones (normally over a

concentration of forces) friendly counter air aircraft are not allowed as all penetrating aircraft are automatically classified as enemy. The typical friendly airspace zone assignment doctrine is shown in Figure 12.

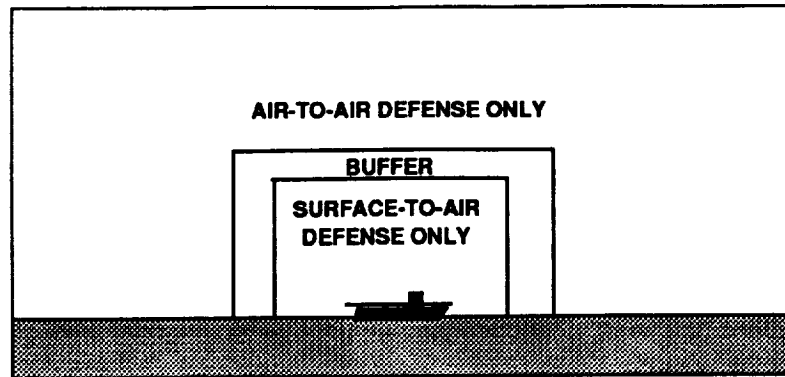


Figure 12 Air Defense Zones

In counter air zones, ground forces are forbidden from engaging aircraft unless a positive enemy identification is made. These engagement rules and airspace assignments could be relaxed to allow ground forces to more aggressively defend themselves from air attack if counter air aircraft were UAVs for two reasons. First, UAVs are more expendable in general. Second, the consequences of mistaking a UAV (as opposed to a manned aircraft) for an enemy and shooting it down are not as severe: a friendly human crew is not lost.

4.1.8 STRATEGIC STRIKE

This mission involves the delivery of nuclear weapons by a coordinated, multi-service strike force consisting of a variety of missiles and airplanes. We envision unmanned vehicles being used as decoys flying preplanned routes. The purpose of these decoys would be to occupy enemy air defenses and cause him to spend defensive weapons attempting to destroy the decoys.

The mission is simple in terms of the technical requirements it imposes on unmanned vehicles and can be performed today. No technology development is required. Technology requirements are similar to those required to support reconnaissance missions.

4.2 Civil Applications

There are a number of interesting applications of IRMA to civil aviation which are envisioned to have high payoffs in operational effectiveness in performing critical missions per dollar spent. The highest payoff involves applications aimed at the war on drugs. Other applications are envisioned in forest fire fighting, search and rescue (SAR), high altitude atmospheric sampling and commercial logging. The most promising applications of IRMA to civil aviation are discussed below.

4.2.1 AIR-TO-AIR DRUG INTERDICTION

Air-to-air Drug Interdiction is the identification, interception, tracking and, finally, apprehension of aircraft and flight crews carrying drugs into the US by civil or military aircraft. Drug Interdiction (unlike surveillance) is aggressive in nature and can occur well outside or inside US border zones.

The US government has been struggling for some time to determine the most effective way of conducting drug interdiction. Several federal agencies have been involved including the Department of Defense, the Customs Service, the Transportation Department (Coast Guard) and the Federal Aviation Agency. None of these agencies has accepted the challenge with enthusiasm. Budgets set aside for supporting drug interdiction have been low. Most all aircraft capable of performing the task are expensive to maintain and operate. The stable of aircraft currently in use include E-2C airborne early warning aircraft, P-3 patrol aircraft, old S-2 tracking aircraft, OV-1C observation aircraft, Cessna Citation business jets, Piper Cheyenne light twins, Hu-60 Blackhawk helicopters, C-130 transports and anything else not currently required to support its primary mission (Reference 1). The Customs Service, Coast Guard and Navy operate these aircraft. A number of the aircraft are expensive to operate and support. A number are obsolete and almost impossible to support from a maintenance standpoint. None of the aircraft were designed for drug interdiction. A large percentage of the flight crews used are trained for other missions and do not perform the drug interdiction mission with enthusiasm: absolute dedication to the mission is a requirement for success for an operator interpreting and classifying targets on a RADAR screen in the pit of an E-2C droning over the Gulf of Mexico for four hours at a stretch.

The E-2C is currently the most capable system for detecting air smugglers. Once a smuggler is detected, however, it has to be intercepted, followed to a landing and it's crew and cargo apprehended. This must be done by interceptor aircraft. In current operations continuously airborne interceptors are not used. They are too expensive by orders of magnitude. Currently, once an E-2C identifies a potential smuggler flying up the Windward Passage (Figure 13) or the Maya Corridor, a request has to be initiated to one of the federal agencies and approved by a ground authority to find and launch interceptor aircraft. Usually the smuggler gets through as the system cannot cope with all of the possibilities as presented in the following list.

1. the smuggler changes course and proceeds to penetrate the border at an area out of range of the assigned interceptor;
2. ground authorities move too slowly and the intercept is not completed;
3. the interceptor has to divert due to fuel shortage before the smuggler lands;
4. relief interceptors cannot be found or coordinated in time;
5. the E-2C loses track;
6. the smuggler penetrates a high density air traffic area (such as the terminal control area (TCA) in San Diego, New Orleans or Miami) with its lights out at night, transponder off, on instrument flight in weather without a clearance and "gets lost" in a maze of airline and general aviation traffic and/or the local FAA Air Route Traffic Control Center and/or Approach Control refuses to permit the interceptor to penetrate the TCA due to heavy traffic.

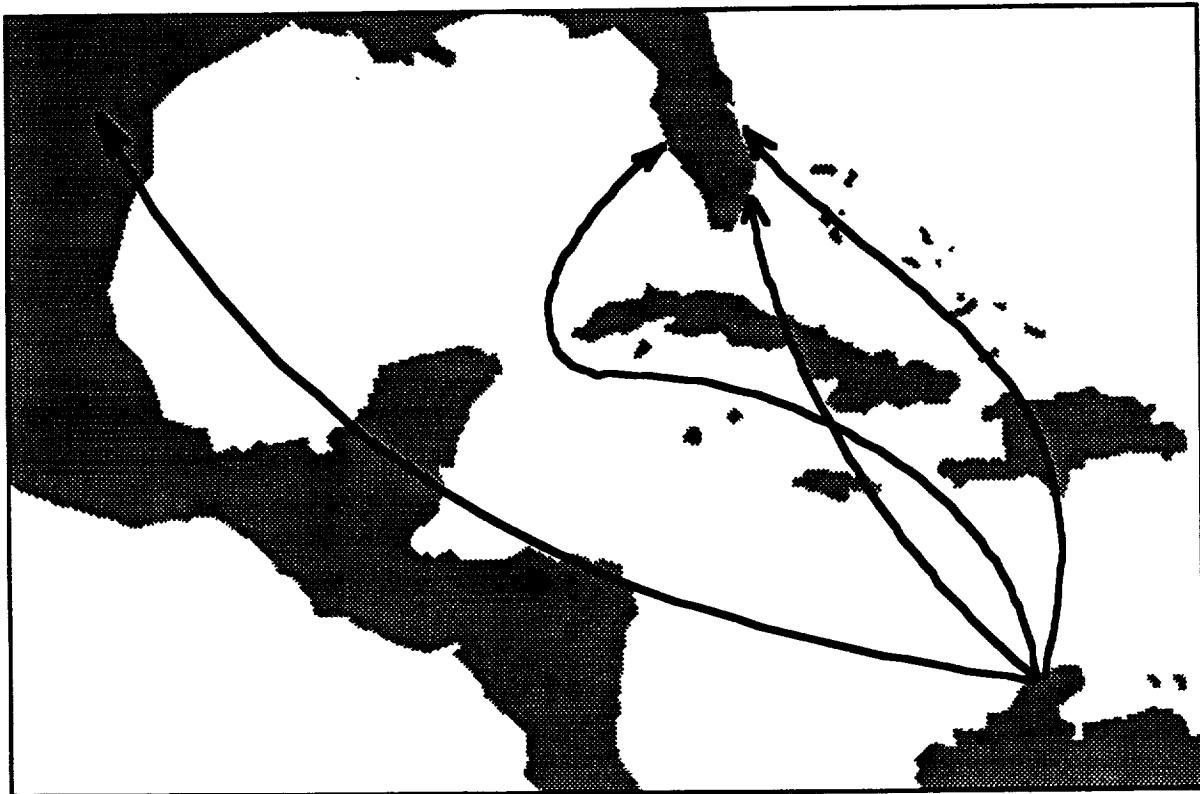


Figure 13 Drug Interdiction Example

Against an “enemy” who has nearly unlimited funds and resourceful flight crews who are paid up to \$250,000 per crew member per flight to successfully evade and deliver their payloads, the United States employs resources which are expensive to support with an extremely limited budget, flies poorly coordinated missions supervised by several less than enthusiastic federal agencies, using “borrowed” flight crews who are not dedicated to the mission. The results are predictable. Air smugglers are apprehended on an average of once or twice a month. (Reference 1).

IRMA has the potential of solving all these related problems. A single high-value, manned command aircraft with airborne early warning RADAR commands a number of low cost UAVs. These robotic aircraft are low cost, medium range, medium performance reciprocating, turboprop or turbofan propelled UAV type aircraft capable of intercepting, tracking, identifying and following possible smugglers. They contain intelligent systems capable of accepting mission level commands and performing autonomous interception, following guidance (station keeping) and tracking. In one concept, RADAR search and initial target acquisition would be provided by the command aircraft and target assignment would be made by the command aircraft to individual UAVs. The concept is shown in Figure 14 below.

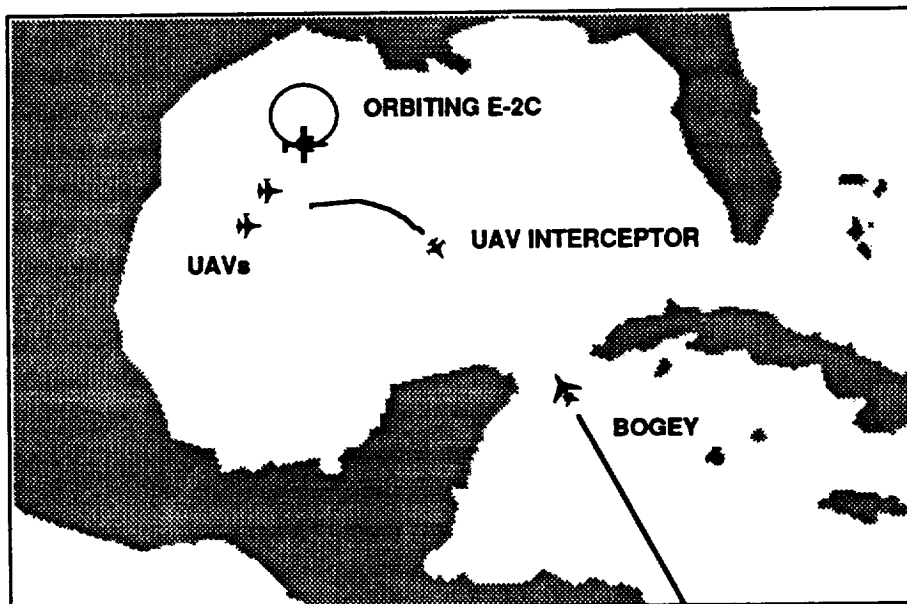


Figure 14 Drug Interdiction - Intercept Concept

In a second concept, the UAVs would perform RADAR search. UAV sensor suites might include video, electro-optical, FLIR, low cost tracking RADAR and possibly, search RADAR. A critical factor for successful interdiction is the ability to keep the robotic vehicles airborne and appropriately positioned continuously while the command aircraft is airborne. This is primarily a budget constraint related to the numbers of UAVs in the system and their maintenance support.

It is envisioned that these types of IRMA systems would provide continuous airborne coverage of the southern, southwestern and southeastern frontiers of the United States.

4.2.2 AIR-TO-GROUND DRUG INTERDICTION

Air-to-ground Drug Interdiction is the identification, tracking and apprehension of personnel in ground vehicles carrying drugs into the US by civil or military aircraft. This mission is performed haphazardly in the US today by a variety of uncoordinated agencies using equipment designed for other purposes. Helicopters with no sensors other than flight crew vision are most often used for the task. They provide no capability for night or bad weather operations. There is no coordinated effort to pursue this mission and no equipment designed specifically for the purpose.

IRMA applied to this mission would include a command vehicle in the general aviation category with little or no active sensors on board. The command vehicle would contain displays, however, which presented information obtained via data link from sensors on the system's assigned UAVs. Lower performance UAVs (possibly helicopter UAVs) would provide following guidance, intercept and tracking of ground targets. The most useful sensor package for these UAVs would include FLIR equipment, electro-optical tracking systems (including automatic tracking spotlights), video cameras and low cost air-to-ground moving target indication RADAR. There is also a case to be made for arming these UAVs with rapid fire cannon. The cannon would primarily be used to contain or stop a ground vehicle from proceeding or an aircraft from taking off until an apprehension team can arrive at the scene. Such a weapon would have to be armed and employment orders given by the command aircraft before a UAV could use it. Employment orders might specify that it be used to fire warning bursts only, fire deadly bursts, fire only in the event escape is imminent, fire only if fired upon, etc.

It is doubtful that these systems would fly continuous coverage over any area. They would in all likelihood be on a ground alert status in numerous strategic locations around the country. They would be capable of becoming airborne in some specified length of time from notification of a mission assignment which might come from any number of participating agencies.

4.2.3 BORDER SURVEILLANCE

Border Surveillance differs from interdiction in that interdiction can begin far beyond US borders into international waters or even into the territory of another country and end well within US borders. Border surveillance represents a second line of defense concentrated in border areas, more passive in nature, but more continuous in its time and area coverage. Aerostat balloons are now being deployed along the southwestern United States - Mexican border to identify air, ground and water vehicles illegally crossing the border. The question is: what is done after the balloon sensor systems (RADAR primarily) detect a potential smuggler? The smuggler has to be tracked to a point where an apprehension can be made. Thus either a coast guard patrol boat, an air interceptor, a ground vehicle or a combination of these must make the intercept. UAVs could be employed to perform the air intercept and following portion of the mission as described in section 4.2.1.

4.2.4 SEARCH AND RESCUE

Search and rescue (SAR) is the coordinated search for downed or presumed downed aircraft, disabled or sunk water vehicles, survivors and their subsequent rescue by aircraft and/or water craft. It is performed by the Coast Guard, Navy, Army, Air Force, Civil Air Patrols and other general aviation resources. SAR often requires incredible human resources which are simply not available. Many of these resources are flight crews flying preplanned search patterns for hours on end. The mission is a natural for unmanned vehicles operating under the command of a remotely located flight controller in another aircraft or a ground station. SAR does not depend on visual sighting alone which is the most difficult from a technical point of view to automate, but SAR also depends on the detection of signals generated by emergency radio beacons, voice broadcasts on emergency radios, flares fired from emergency flare guns or tracer ammunition. These types of emergency signals are more easily sensed than simple visual sightings of crash sights. Thus, the sensor problem on SAR UAVs is less difficult technically than the identification problem for unmanned interceptors. SAR UAVs deployed in force could cover wide search areas at a time thus significantly increasing coverage. The concept is shown graphically in Figure 15 below.

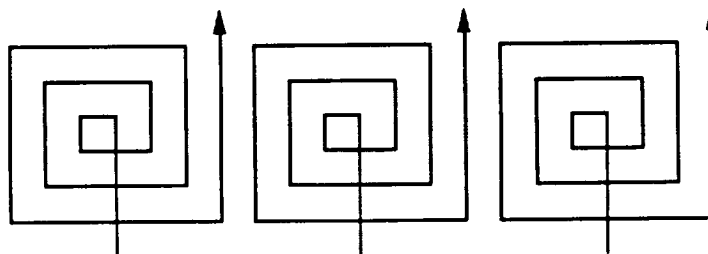


Figure 15 Search and Rescue Pattern Flown by Multiple UAVs

4.2.5 FOREST FIRE FIGHTING

Forest Fire Fighting herein refers to the coordinated attack on forest fires by specially equipped aircraft and specially trained crews employed either by the forest service or by civilian contractors who provide this service to states and the federal government. It is a very dangerous business. Tanker aircraft must often fly through fire and smoke to effectively drop fire retardant chemicals. It is much like low altitude bombing in tactical military circles.

We envision UAVs as tanker aircraft being controlled by airborne flight controllers in orbiting coordination aircraft. The concept is shown in Figure 16 below.

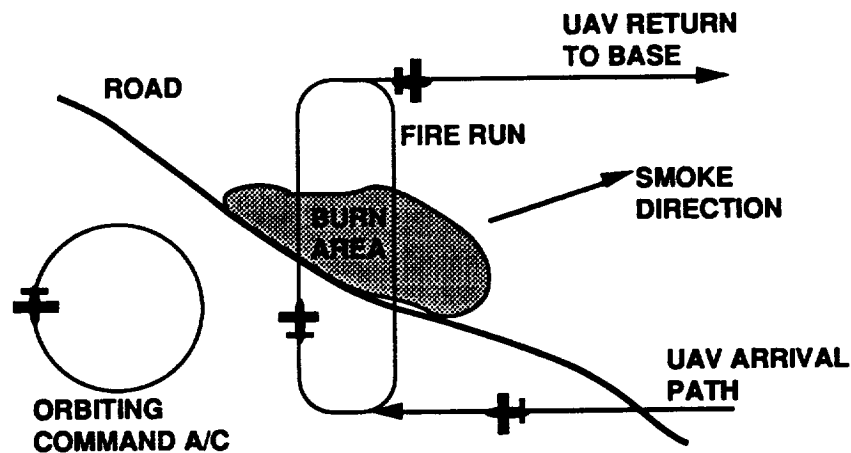


Figure 16 Forest Fire Fighting Application

The unmanned aircraft would be rather large tanker aircraft containing a significant level of machine intelligence on-board and controlled in the same manner as automated wingmen in the tactical applications. That is: high level commands are issued to the unmanned tanker via UHF or VHF voice radio. Responses and other data are transmitted back to the controller aircraft via internetted data link. Technologies required are expert systems and natural language understanding.

It is possible to envision a system which does not require natural language understanding of voice communication as an interim first system for this application. Unmanned tankers could be controlled at a lower level by pilots in manned aircraft flying a detached wing position on the tanker. The controller aircraft would be small general aviation aircraft with sufficient performance to fly wing on the tanker being controlled. The controller could avoid the very low level fire and smoke environment which the tanker would fly through. This type of control has been used by the military for years with expensive, large target drones. Twenty years ago, the Navy was controlling Regulus II target drones to field landings on San Nicholas Island off the California

coast using T-1A aircraft as the drone controllers. The two seat T-1A was flown in a position high on the right wing of the drone. The drone was controlled to a field landing by the crewman in the back seat of the T-1A. Control of the drone was passed to a ground controller on touchdown as the T-1A performed a low pass over the field. This forest fire fighting concept is depicted in Figure 17 below.

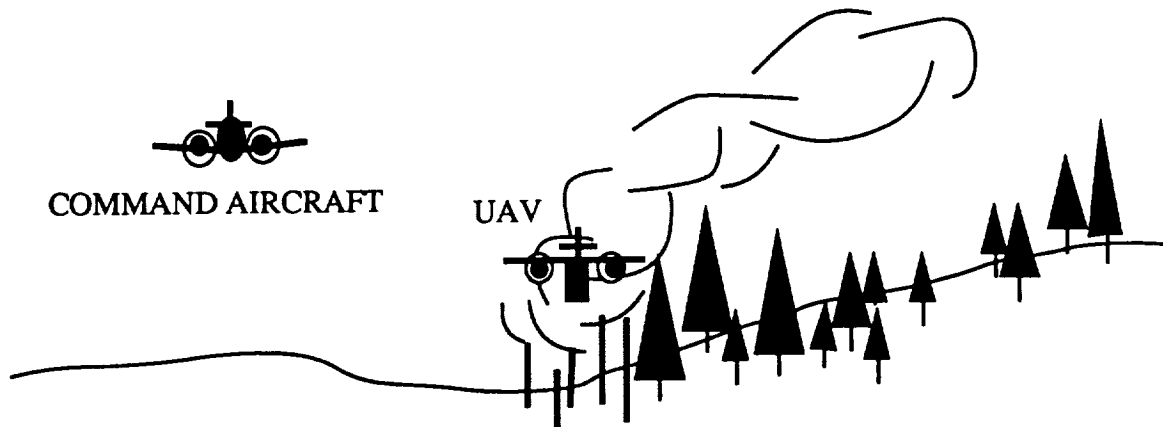


Figure 17 Alternate Forest Fire Fighting Concept

4.2.6 HIGH ALTITUDE ATMOSPHERIC SAMPLING

In this application UAVs would be used to record atmospheric data associated with violent storms and other atmospheric phenomena. These missions are often dangerous and could easily be performed with UAVs possessing machine intelligence on-board. The aircraft would be responsive to a ground controller and capable of recovery in the event of communications failures.

4.2.7 COMMERCIAL LOGGING

One of the most expensive parts of logging operations is the removal of large logs from remote areas. The process requires extensive forest road building, and a fleet of tractor trailers. Many forest areas are unloggable because roads simply cannot be built to access the area. Even areas relatively close to a logging road can cause insurmountable problems because the presence of a hill, ravine or other obstacle makes dragging a log to a trailer impossible.

Logging companies have investigated the use of heavy lift helicopters to deliver logs from the fall point to a trailer in the past. The idea has been generally rejected not on the basis of a cost analysis, but because no one has ever conceived of a satisfactory way of controlling the motion

or position of a very large log as it is extracted from the forest by helicopter lift, or as it is lowered from a helicopter and loaded onto a trailer. The operation is considered unsafe because of the lack of a way to precisely and reliably control a suspended log in a tight forest environment.

We propose that a two ship formation of helicopters, one manned and one unmanned, could do the job and provide the precise log positioning required during both the extraction and loading operation. The concept is shown in Figure 18.

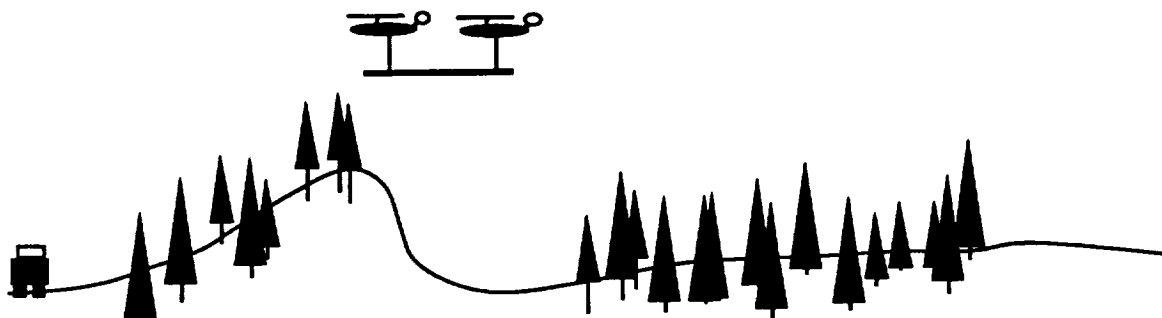


Figure 18 IRMA Logging Concept

During transit with a suspended log, the manned helicopter would be flown by the pilot. The UAV helicopter would fly automatic formation on the manned aircraft. During extraction and loading, both helicopters would be under the remote indirect control of a ground operator. The ground operator would issue direct positioning commands to the two ship system by observing the position of the log. That is, the ground operator commands log position and orientation. His commands would be translated to a guidance algorithm executing in a digital computer in the manned helicopter which, in turn, would issue autopilot and hoist system commands to both helicopters taking into consideration terrain, vehicle performance, pilot inputs, combined vehicle dynamics and ground operator inputs. The pilot in the manned helicopter could override the ground controller or set limits on minimum altitude, lateral movement or heading based on the terrain in the immediate vicinity.

4.2.8 POLITICAL AND MANAGEMENT ISSUES ASSOCIATED WITH CIVIL APPLICATIONS

All civil applications of IRMA share a common set of technical, political and interagency cooperation problems associated with air traffic control and instrument flying conditions. These problems are rooted in certain fundamental issues related to flying unmanned aircraft in the same airspace with manned aircraft containing the flying public and to flying unmanned aircraft over populated areas. Safety of flight issues are involved. All of these applications must provide

operational capability in all weather conditions, day and night and in crowded airspace to be effective, but the issues of air traffic control and instrument flying will require resolution even if a specific application is meant to be operational only in day/VMC conditions. The resolution of the political and interagency issues associated with the operational employment of civil IRMA applications present hurdles far greater than the technical issues involved. The problem is rather similar (but more severe) than the problem of deploying microwave curved path landing systems (a technology developed by NASA a decade ago) in the US in place of Instrument Landing Systems (ILS) and the problem overcoming current restrictions on supersonic flight over the US for air transports.

The Federal Aviation Agency (FAA) is responsible for insuring air safety in controlled airspace over the US. Virtually all airspace over the continental US is now controlled. The only areas over which the FAA does not exercise control are restricted and prohibited areas in which the FAA has delegated control to local military commands during preagreed hours of the day. As a result, all civil IRMA operations conducted over the continental US will require FAA approval and significant cooperation. IRMA unmanned aircraft must be capable of accepting and flying instrument flight plans, responding to FAA controller commands and flying instrument approaches to landing. This may be done through the manned command aircraft or via UHF radio (voice) to the unmanned vehicle. The FAA will in all likelihood require that unmanned IRMA airplanes be instrument qualified in equipment and proficiency with or without the presence of the command aircraft as a precondition of their use over the continental US. It is true that the FAA is not responsible for the separation of aircraft operating under VMC conditions, that general aviation aircraft are not required to file flight plans for VFR flights, and that general aviation aircraft or pilots do not have to be instrument qualified, however, unmanned IRMA aircraft represent a new operational concept with no applicable precedents in operational employment. Their widespread use would arouse public concerns for aviation safety to which the FAA would respond.

These issues, however, would not have to be faced until the advanced development of a production system was imminent. In research, exploratory development and flight demonstration, prototype systems would be flown in military restricted areas. Operational evaluations of prototype systems could be conducted in controlled airspace outside of restricted areas by designating all unmanned aircraft as experimental: a ploy the FAA would put up with for a limited period of time. Finally, there are no restrictions on operations in uncontrolled airspace or warning areas over water such as the airspace over the Gulf of Mexico.

5.0 ADVANCED TECHNOLOGY CONTENT

In this section the advanced technologies required to build IRMA systems are described and the state-of-the-art in each technology is presented.

5.1 Technologies Required:

The latest advances in the following technologies are required to develop and flight demonstrate all of the IRMA systems described above:

1. Intelligent Systems
 - a. Real-time expert systems
 - b. Cooperating expert systems
 - c. Distributed expert systems
 - d. Monitoring & diagnostic expert systems
 - e. Expert system - guidance & control integration
 - f. Fault tolerant/gracefully degrading expert systems
 - g. Expert system verification & validation
 - h. Natural language understanding
 - i. Speech understanding and synthesis
 - j. Image understanding
 - k. Sensor fusion
 - l. Human centered automation
2. Software Development
3. Sensors
 - a. Low cost, low maintenance tracking RADAR
 - b. Low cost, low maintenance, high resolution FLIR
 - c. Electro-optical tracking
4. Communications
5. Unmanned Airborne Vehicles
6. Airborne Computers
7. Navigation
 - a. Low cost inertial navigation
 - b. Inertial navigation alignment and updates
 - c. Terrain avoidance
8. Guidance & Control
 - a. Collision avoidance
 - b. Automated controlled intercept and station keeping under both visual and instrument conditions
 - c. Maneuver autopilot

- d. Automated takeoff and landing (including instrument landing)
- e. G&C integrated with intelligent systems
- f. Optimal trajectory generation and tracking

Figure 19 depicts the IRMA supporting technologies graphically.

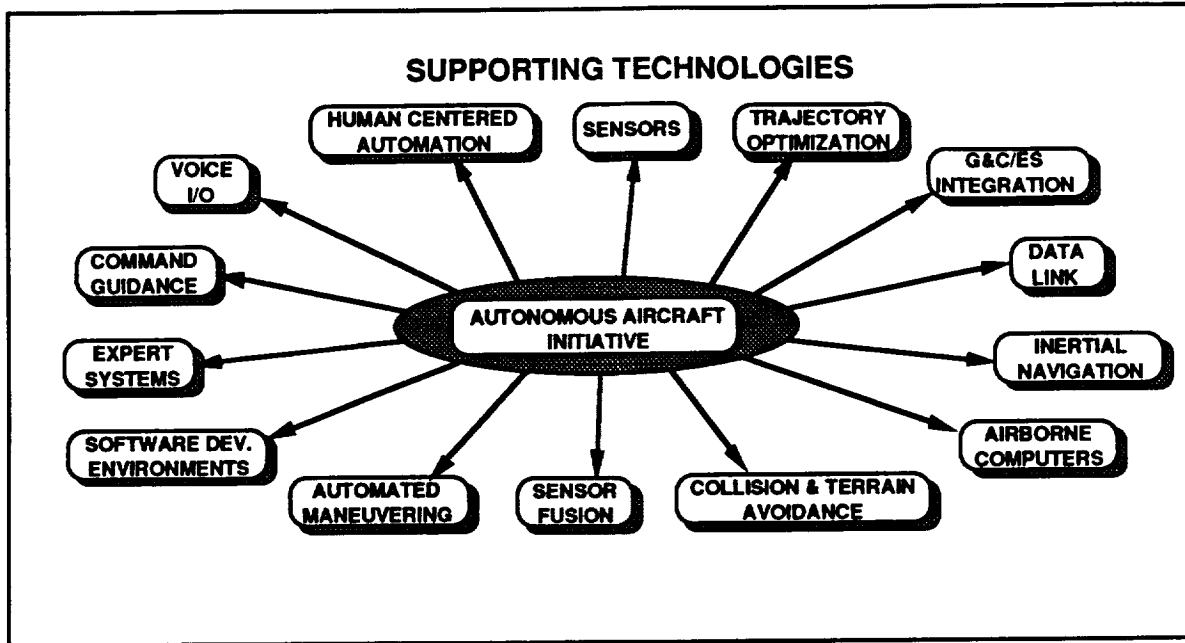


Figure 19 Supporting Technologies

5.2 Status of the Technologies

The current state-of-the-art in each technology area is discussed in this section.

5.2.1 INTELLIGENT SYSTEMS

Intelligent systems are systems which employ Artificial Intelligence (AI) technologies to provide some degree of machine intelligence to the system's responses to external stimuli. The primary AI technologies are:

1. Expert and knowledge based systems
2. Natural language understanding
3. Speech synthesis

4. Voice recognition
5. Robotics
6. Image understanding
(computer vision)

The problems that are being addressed by AI technologies can be thought of as a triangle (Figure 20). The triangle's apex represents difficult time-sensitive, critical decisions that must be made frequently involving life-threatening repercussions. The triangle's center represents less difficult problems. The triangle's base addresses ordinary and mundane (but important) problems. While relatively straightforward, problems in the triangle's lower part can be time consuming for human beings. Expert systems that help solve these straightforward problems give us more time for nonroutine problems. More sophisticated AI solutions in the triangle's center are still evolving in the R&D community. Finally, at the triangle's apex, we deal with problems not readily solved and ones that should not be attempted in the near term.

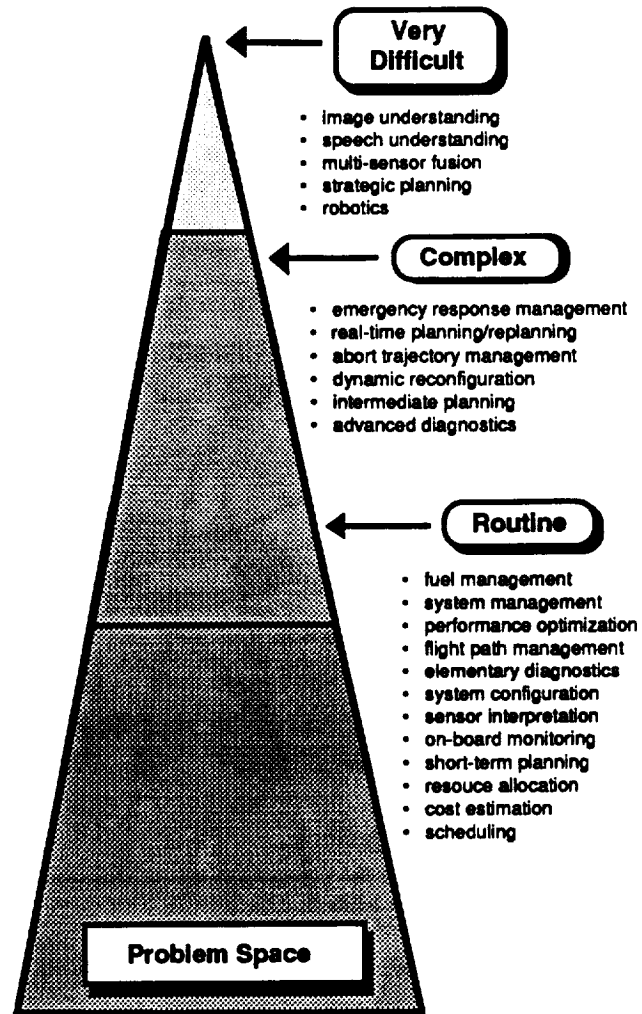


Figure 20 The AI Triangle of Problems

Expert and Knowledge Based Systems

The wide spread transition of early DARPA, DoD, NSF and NIH expert system technology to the user community makes this very attractive for some of the problems anticipated for IRMA. The more straight forward problems of resource allocation, decision aids, cost estimation sensor interpretation, target motion analysis, and monitoring, navigation aids and elemental planning are prime candidates for IRMA to use expert systems. These are the problems that would be found in the lower portion of the triangle. References 2 through 7 describe expert systems and other components of AI technology in more detail. The use of distributed problem solving that allows the communication and cooperation of expert systems is fast becoming an important technique. Very complex problems can be broken into smaller problems that are addressed by small to medium sized expert systems. This approach has been used to distribute

complex planning processes to small expert systems that work as a team to solve the original large problem. In addition, distributed, communicating, cooperating expert systems have been shown to be a smart way to approach the complex problem of multiple sensor fusion. The risk associated with this technology is relatively low and the payoff for IRMA is very high. Expert systems and some aspects of distributed problem solving are ready for IRMA applications. Other specific current applications of expert systems which have an effect on IRMA are discussed below.

1. Monitoring and Diagnostics Expert Systems.

Monitoring and diagnostics expert systems are in everyday use today in a number of scientific and engineering fields. Diagnostic systems have been successful in applications including medical diagnostics, electronic and mechanical troubleshooting, manufacturing and production analysis, nuclear power plants and remote diagnostics. DoD programs have been focusing on the analysis and automatic generation of troubleshooting trees as well as the recommendation of additional test points if required. Expert system monitors and diagnosticians are in advanced development for system's monitoring and trouble shooting in aerospace vehicles in the DARPA sponsored Pilot's Associate Program, Space Defense Initiative and individual programs by all three services.

2. Decision Aiding Expert Systems

Decision aiding is another application which is currently receiving attention in tactical military aviation. The Pilot's Associate Program contains expert system decision aids for tactical aircraft flight crews.

3. Knowledge and Data Base Management Expert Systems

The use of expert systems to facilitate queries of large complex data bases can aid the IRMA applications. The machine can focus the queries, understand the underlying questions and then gather the appropriate data. The use of natural language can make the formulation of the questions much easier.

Natural Language Understanding

This AI technology has made a great deal of progress in the last few years. Natural language interfaces to complex data bases have aided the human to make sophisticated queries and receive comprehensive replies. Computer understanding of free form text is becoming routine in very narrow domains and a very specific message traffic. This natural language capability will be expanded to multiple messages and wider domains in the next three-to-five years.

Speech Understanding and Synthesis

The use of natural language applied to speech understanding and synthesis is a technology that will take several years. The development time is required to marry present speech systems with deeper understanding natural language techniques. The final product will be a large vocabulary, continuous speech, speaker independent capability. This technology can also be used to generate textual responses and convert it to speech for easy man-machine interfaces.

Image Understanding (Computer Vision)

The use of AI expert systems as visual sensor interpretation is an active branch of university research. At this time, there are no robust systems that are available for IRMA. It appears that this area of research will require at least six years. The technical area is becoming known as "computer vision". The technology is required to perform visual identification in military and civil applications involving unmanned vehicle intercepts. Vision systems are under development for intelligence and situation assessment applications and for road tracking in the DARPA sponsored Autonomous Land Vehicle Program. Vision systems are in production use today in industrial contexts to inspect integrated circuits and to manipulate parts, but unfortunately, fast and reliable vision systems are very difficult to achieve. General purpose vision systems, which would be able to operate in a multitude of domains, are not possible today. In order to process visual data, the physical data must be extracted from the image; the significant objects must be labeled; and the objects must be described symbolically. A great deal of domain-specific knowledge, along with a processing mechanism, is needed to tie the very low-level image data (generally at the pixel level) to the objects presenting the image. A central goal of vision research at this time is to determine how high-level knowledge and inferential procedures contribute to the vision process and how to implement algorithms (Reference 4).

Sensor Fusion

The combination and fusion of multiple sensors and data sources is important to relay a true assessment of any given situation. In expert system aided sensor fusion, various sensor outputs are combined using distributed expert systems that interface with the individual sensors. The communication of data allows suspect sensors to be tested.

This application of communicating expert systems to fuse multiple sensor data into a cohesive picture is still primarily in the early stages of research and development. There are many hopeful indications in the Navy, Air Force, DARPA, FAA and private industry where working prototypes are addressing aspects of this problem. The use of expert systems is combined with conventional pattern recognition, signal processing and parameter estimation to provide a synergistic solution. IRMA will undoubtedly employ multiple sensors for navigation, space

positioning, atmospheric conditions, weather detection, trajectory control, etc. An expert system approach to sensor fusion may provide payoffs comparable to those provided by traditional Kalman and maximum likelihood filtering. Payoffs may be of particular benefit in situations where certain sensors malfunction and filter reconfiguration or data reconstruction is required.

Human Centered Automation

Human centered automation is a newly coined word for applications of automation technology where the human operator exercises control. The automation technology is applied to make best use of the human's presence. In most applications this means allowing the human to operate as a systems manager as opposed to a systems integrator or operator. The IRMA applications all require human centered automation principles to be applied in design to result in useful systems. In this past research and development in this area has been pursued under the guise of pilot-vehicle interface technology and has been conducted largely by groups working under a human factors banner. The technology has been applied in various military R&D programs in recent years.

5.2.2 SOFTWARE DEVELOPMENT

Software development is included as a required technology for IRMA applications because work is required to build the environments appropriate to develop airborne applications software which includes AI technologies. Airborne software must execute quickly and produce verifiable results. A new emerging technology for expert system development for example would use an expert system shell with an inference engine for development but would produce compiled code without the inference engine for the airborne computer.

AI development languages are going through a transition. LISP is no longer the preferred language for developing AI applications code. It is being replaced by other higher order languages including C and Ada. The development of LISP processors for airborne computing has been abandoned as it has for practically all other applications.

Parallel processing is still a viable processing alternative for airborne computers. Commercial parallel processors are available which use transputer technology. NASA is developing an airborne research computer using transputer technology.

5.2.3 SENSORS

Sensor technology is central to realizing applications of IRMA. These systems will require low cost RADAR, FLIR, video systems and electro-optical tracking systems.

Low Cost, Low Maintenance, Light Weight Tracking RADAR

Light weight modular RADAR systems have been under development at the Massachusetts Institute of Technology's Lincoln Laboratory for some time. The developments were sponsored by DARPA. A 100 lb version was flight demonstrated in an Amber unmanned aerial vehicle in 1988. With the addition of an inertial navigation package, data link and communication the entire package weighed 175 lbs. This system is a pulse doppler ground mapping and ground vehicle identification system meant to be used to locate and identify ground targets for a battlefield commander. The system transmits in the Ku band using a 4 x 1 ft antenna. The design also permits X, S and L band operation with a module change. It is clear from this work that light weight RADAR systems for air-to-air search and tracking, and air-to-ground search and identification can be built with today's technology to support IRMA applications.

Low Cost, Low Maintenance, High Resolution FLIR

Forward Looking Infrared sensors are standard equipment in today's tactical aircraft. They are used primarily for night operations. Their expense is likely to inhibit their use in UAV aircraft. Their employment in IRMA applications is required to interdict ground vehicles and water craft at night.

Electro-optical Tracking

Electro-optical tracking systems are in use today in Walleye and Maverick weapon systems. These weapons employ contrast ("edge") detectors from video cameras to generate tracking errors and produce guidance commands. Such trackers would aid in target identification and in completing the final phase of an intercept in military IRMA applications. In the civil drug interdiction application an electro-optical tracker would also aid in target identification and in station keeping (trailing) a target after an intercept is performed. In Figure 21 a Walleye video display is depicted. The display is generated from a video tracking camera in the nose of the Walleye missile and is shown on the parent airplane's multifunction cockpit display. The pilot obtains a visual "lock" on a target by positioning an area of contrast (usually an edge of a building, a window or the outline of a vehicle) in the center rectangle and pulling a trigger. From that point on, through weapon release, and flight to impact, the walleye tracks the lock point frequently refining that point as the target size grows. The system could be used to track and fly stationkeeping on intercepted aircraft in the civil drug interdiction example. Initial lock and relock in the event of an unlock could be obtained from another tracking system - a RADAR tracker for example.

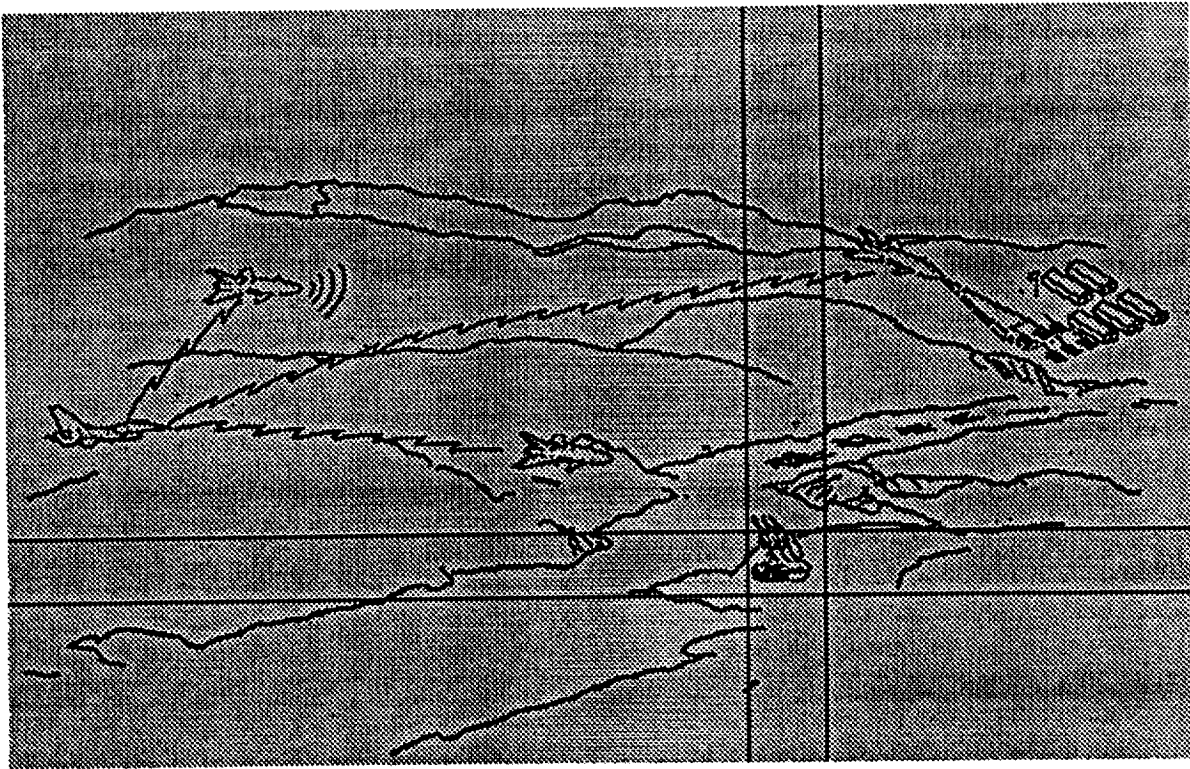


Figure 21 Walleye Electro-Optical Tracker

5.2.4 COMMUNICATIONS

Internetting has been flight demonstrated between airplanes using a millimeter-wave data link. It is not in use in production military aircraft as yet. Internetting is the concept of sharing avionics bus information between aircraft in a formation. The concept is required to support the large amounts of data which an unmanned vehicle must send to a command center (another airplane or ground station) for monitoring purposes.

5.2.5 UNMANNED AIRBORNE VEHICLES (UAV)

A number of UAVs are now either in production or advanced development which have the capability of supporting many of the IRMA applications discussed in this paper. The most promising of the vehicles are discussed below.

Brevel (mini-RPV)

Brevel (Reference 8) is a development of Eurodrone, a joint venture established by MBB of Germany and Matra of France. This mini-RPV is scheduled for production in 1995. Powered by a two cylinder engine with a pusher propeller, Brevel will be capable of 3.5 hour missions. Its primary mission will be surveillance and artillery spotting. It will be equipped with a FLIR, a video camera and a jam resistant data link. MBB is also developing two attack versions of the RPV. The first is an antiradar RPV equipped with a wideband antiradar seeker. The second, is an antitank RPV equipped with a dual mode sensor to provide target acquisition and terminal guidance.

Brave 200 (mini-RPV)

The Air Force is continuing tests of the Boeing Brave 200 mini-RPV (Reference 8). It is an antiradar RPV which will probably not be procured due to DoD's stronger interest in Tacit Rainbow.

Tacit Rainbow (mini-RPV)

Tacit Rainbow (Reference 8) is a Navy sponsored development by Northrop Corporation.

Flash (mini-RPV)

Flash (Reference 8) is a multipurpose RPV which contains a video camera and a data link. Flash is powered by a 24 hp engine and has a 4 hour endurance. It is 12 feet long and has a payload of 92 lbs.

MART (mini-RPV)

MART (Mini-Avion de Reconnaissance Teleilote) (Reference 8) is developed by Alpylles of France for the French Army. It is used for Surveillance and reconnaissance. It supports a video camera and a data link which can transmit video imagery 33 miles. It has an endurance of 3.5 hours.

Impact

Impact is a development of Israel Aircraft Industries. It is an upgraded version of Pioneer and is capable of 12 hour endurance and mission payloads of 400 lbs.

Model 350 RPV

Teledyne Ryan's Model 350 RPV (Reference 8) is a high performance, medium range RPV powered by a turbofan engine. It has a maximum speed of 0.91 Mach and a cruising range of 1000 miles. It has a wing span of 10 feet and weighs 1650 lbs.

5.2.6 AIRBORNE COMPUTERS

The computational throughput available in digital flight computers occupying a given volume has been doubling every year for a decade. Digital mission computers and flight control computers are now in use in production airplanes as well as smaller digital computers for localized tasks in avionics suites such as display generation, environmental control, etc.

The computational power required to support on-board intelligent systems in UAVs for IRMA applications, however, is not available today. We estimate that the throughput requirements for IRMA applications will be from 100 to 500 Mwets depending on the application. The ROLM HAWK and NORDON MILVAX, two airborne digital computers available today which occupy less than one ATR, are capable of 1.44 and 2 Mwets respectively. By geometric progression 500 Mwets will be available commercially in eight years in an ATR volume.

There has also been a shift lately away from symbolics (LISP) processors for all applications including airborne computing. Until recently the aerospace community pursued the development of LISP processors for hosting and executing knowledge based system code in embedded applications. This activity has been reduced significantly in the last two years. The scientific and engineering thought now is that conventional processors are appropriate for all computing applications.

Recently, however, the development of transputer technology promises to increase available throughput significantly in airborne computers. Transputers are single chip, 32 bit processors designed specifically for use in parallel networks. Typically they are mounted four processors to a computer board. A four processor board has a throughput capability of 16 Mwets. NASA Ames-Dryden is supporting a Phase II SBIR with SPARTA, Inc. to develop a transputer based airborne research computer for the NASA based F-18 demonstration aircraft.

5.2.7 NAVIGATION

On-board navigation systems assisted by external updates are capable today of supporting all IRMA applications previously presented. UAVs do not require extremely accurate inertial navigation for most IRMA applications for the following reasons:

1. The Global Positioning System (GPS) will be operational before IRMA applications become operational. Thus, frequent GPS updates to the inertial system's navigation solution will be possible.
2. If GPS is not operational, or if GPS communication must be suppressed for coactness or some other reason, then UAV navigation updates may be obtained from the manned lead aircraft via the internetted data link. This presumes that the manned aircraft possesses a high quality inertial system updated less frequently with GPS or updated via navigation aids, terrain features and/or landmarks. This also presumes that the manned lead aircraft tracks and, therefore, knows the position of the UAVs whose low quality inertial systems it must update. This tracking could be accomplished with the millimeter-wave communication link used for the internetted data transfer.

Low Cost Inertial Navigation

Low cost inertial navigation systems are available today with the necessary accuracy to support IRMA applications.

Inertial Navigation Alignment and Updates

We envision that the normal mode for obtaining navigation updates to a UAVs inertial system will be from GPS. A second mode will be from manned lead aircraft through the internetted data link. In this second case, the update would come from the lead aircraft's inertial system which, presumably, is a higher grade system. Lead's inertial system updates could be from GPS (at lesser intervals than UAV inertial updates), navigation aids, terrain features or landmarks.

Terrain Following and Avoidance

Terrain following is defined as maintaining a set vertical distance from terrain by constantly adjusting a vehicle's altitude. Automatic terrain following system have been operational for a number of years. Terrain avoidance is defined as avoiding terrain by a set

distance through both altitude and horizontal flight path adjustments. Automatic terrain avoidance has been the subject of a number of government sponsored R&D programs over the past decade. Automatic terrain avoidance has not yet been flight demonstrated, nor do any production aircraft possess such a system. The most advanced work to date has been that sponsored by WRDC in the mid 1980s and by NASA Ames-Moffett on the Helicopter Automated Nap-of-the-Earth Flight Program.

5.2.8 GUIDANCE AND CONTROL

Guidance and control technology is a relatively mature technology which is capable of supporting IRMA applications now. The integration of G&C and knowledge based systems technologies is not mature, however, there are no show stoppers other than the computer throughput required to support the high throughput computer programs which will have to be executed.

Areas requiring development are:

1. Verification and Validation of programs which have knowledge based system content.
2. Collision avoidance systems
3. Maneuver autopilots
4. The integration of intelligent systems with guidance and control systems

In addition, neural networks technology presents potential advantages which need to be explored. A neural network based autopilot has been demonstrated in simulation at NASA Ames-Dryden.

Collision Avoidance

Collision avoidance systems are in advanced development for airliners at this time. The type of system required to support IRMA applications, however, is likely to be quite different from a hardware standpoint. If millimeter-wave internetted data link is used in IRMA applications, range and heading are available between each aircraft in a manned aircraft/UAV mixed formation. This "free" information could be used to support a collision avoidance system. Each UAV would continually execute a collision avoidance algorithm and generate guidance commands to the maneuver autopilot to continually avoid other aircraft in the formation. We do not anticipate that automatic collision avoidance would be provided between UAVs and other

aircraft not a part of the formation. Millimeter-wave hardware for collision avoidance is available today. The collision avoidance algorithm involved would require considerable development.

Automated Controlled Intercept and Station Keeping Under Both Visual and Instrument Conditions

Automatic intercept and station keeping on a bogie are tasks which are within the capabilities of current technology. Solutions to these tasks are required to implement the air-to-air drug interdiction, intercept, combat air patrol and counter air IRMA applications where no manned aircraft operate in the immediate vicinity. Intercept often means rendezvous in these applications, that is, in the end game, relative motion between interceptor and bogie must be reduced to zero. Station keeping means tracking the bogie and maintaining a given position with respect to it after a rendezvous is completed. The task requires the UAV to possess wide angle tracking radar and a rather sophisticated guidance algorithm.

Rendezvous and station keeping (formation flying) are also requirements in any IRMA application between aircraft in an IRMA formation. However, the task is much simpler from a hardware viewpoint because both lead aircraft and UAVs are equipped with the appropriate hardware to do the job (millimeter-wave data link): tracking RADAR is not required.

Maneuver Autopilot

Maneuver autopilots are within the current state of the art in G&C. The HiMAT vehicle demonstrated at NASA Ames-Dryden used a maneuver autopilot developed by NASA. IRMA applications require this function to execute all types of operational maneuvers.

Automated Takeoff and Landing (including instrument landing)

Automated takeoff and landing systems are operational now with the exception of the takeoff and landing roll. The takeoff roll problem is easily solved by catapulting UAVs. The equipment used would be designed after catapults used in the U.S. Navy for the last forty years. The system requires specially designed nose landing gears and holdback fittings on the UAV.

The landing problem is most easily solved by using field arresting gear to limit the UAVs landing roll. Field arresting gear has been used by the Navy for forty years as a by-product of the aircraft carrier arresting gear. We envision UAVs being equipped with tailhooks similar to those used by carrier aircraft.

G&C Integrated with Intelligent Systems

This technology addresses the translation of commands from a manned aircraft to trajectory generation and control system inputs. The concept most widely proposed for this type of integration is that knowledge based or expert systems function as outer loops to a guidance and control system. The hierarchy of systems required to fly a UAV are shown in Figure 22 below.

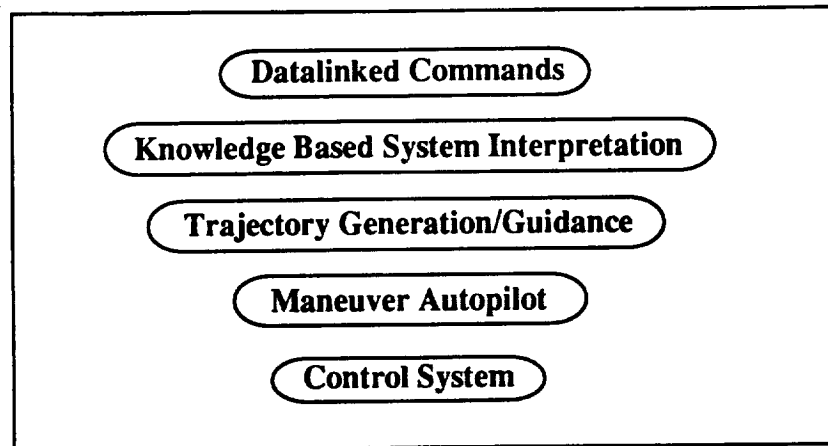


Figure 22 Generic UAV Path Control Hierarchy

The technology is capable today of implementation IRMA applications, however, considerable design and software development would be necessary. A flight planning system known as Automated Flight Test management System (ATMS) was implemented at NASA Ames-Dryden which featured an integrated maneuver autopilot driven by an expert system (Reference 9).

Optimal Trajectory Generation and Tracking

Applications of optimal control theory to trajectory generation and tracking have been the subject of considerable research for thirty years. Trajectory generation is generally considered an open-loop optimization problem solved by a digital computer algorithm using one of a number of gradient methods to produce an optimal sequence or optimal control time history. Optimal tracking, on the other hand, is generally formulated as a linear regulator problem with a mathematical closed form solution in the form of a feedback control law. The trajectory generation problem is much more difficult because it requires considerable computational throughput. It has not been implemented in on-board computers in any production aircraft.

6.0 PROGRAM DEFINITION PLAN

6.1 Program Definition Process

Figure 23 depicts the process which is being pursued to define a new Autonomous Aircraft Initiative for NASA.

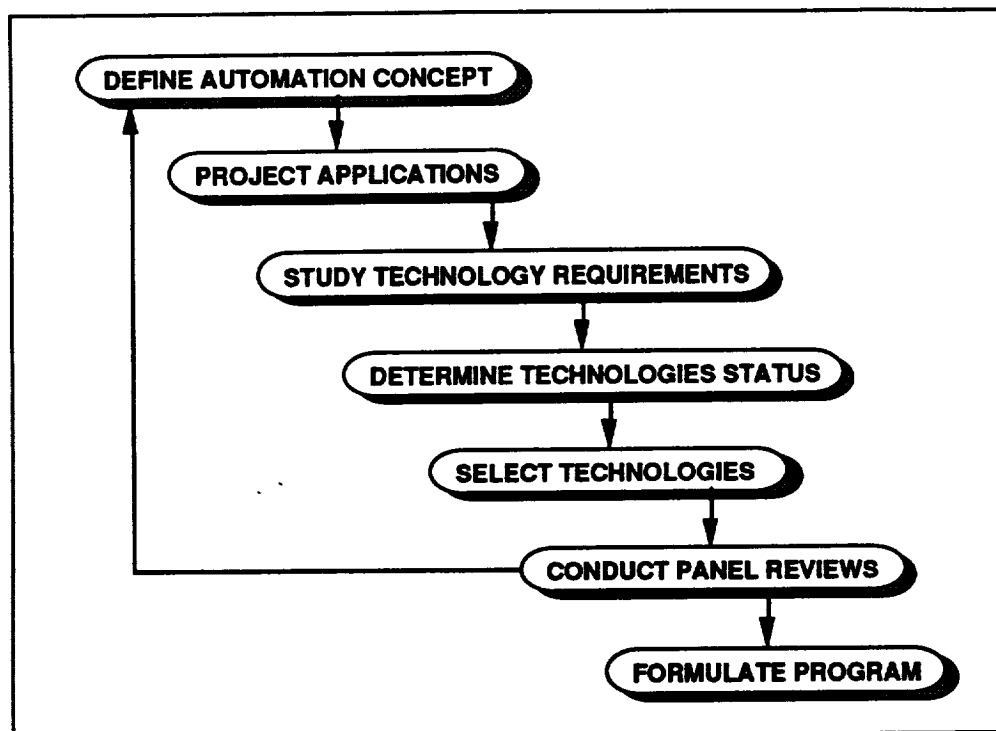


Figure 23 Program Definition Process

This process is on-going. This report addresses the top four items down through “determine technologies status”. The remaining three items have not been addressed. Progress to date has been presented to NASA Headquarters (Doug Arbuckle), NASA Ames-Moffett (Greg Condon and Dallas Denery) and NASA Langley (Ray Hood and Jerry Elliott). The results of those reviews are contained in the Appendices to this report.

At the suggestion of Greg Condon and Dallas Denery of NASA Ames-Moffett, the second to last item in Figure 23 was added. This involves inviting a panel of experts to review the proposed initiative, help define a specific scenario and help select the specific area for technical development and flight demonstration. They suggested that this panel be composed of specific individuals from DoD laboratories and R&D field activities, the aerospace industry,

NASA centers and headquarters. They suggested that this committee meet two or three times to review progress on the development of the initiative. They claimed that this tool worked well for them in defining the Helicopter Automated Nap-of-the-Earth Flight Program. No progress has been made on this task.

6.2 Related Non-NASA R&D Programs

Several of the most prominent R&D programs in aircraft automation are summarized in the following paragraphs. Their relationship to the automation concept proposed herein is presented in each case.

6.2.1 PILOT'S ASSOCIATE PROGRAM

This ambitious program is sponsored by DARPA and WRDC. The goal is to build and demonstrate in simulation an AI based, intelligent, computer "associate" to aid the human flight crew in performing a number of related tasks in a tactical aircraft. The tasks are:

1. System status monitoring and fault diagnosis
2. Mission planning
3. Tactical planning
4. Situation assessment

No flight demonstrations are planned in this program. The program has been in existence for five years and considerable progress has been demonstrated.

Most of the Pilot's Associate technology has bearing on the proposed NASA automation initiative. That which does not have bearing are the high level tasks of mission and tactical planning. These tasks are done in IRMA applications by the manned aircraft or ground controllers. Thus, the Pilot's Associate program is more ambitious than the proposed new NASA automation initiative from an AI technology point of view. On the other hand, the Pilot's Associate program does not include flight demonstrations, whereas, incremental flight demonstrations are a cornerstone of the NASA initiative. In addition, the Pilot's Associate is meant to be an advisor only. In IRMA applications the intelligent system is fully responsible for flying the UAV which is hosting it. A top level functional block diagram of the Pilot's Associate is shown in Figure 24.

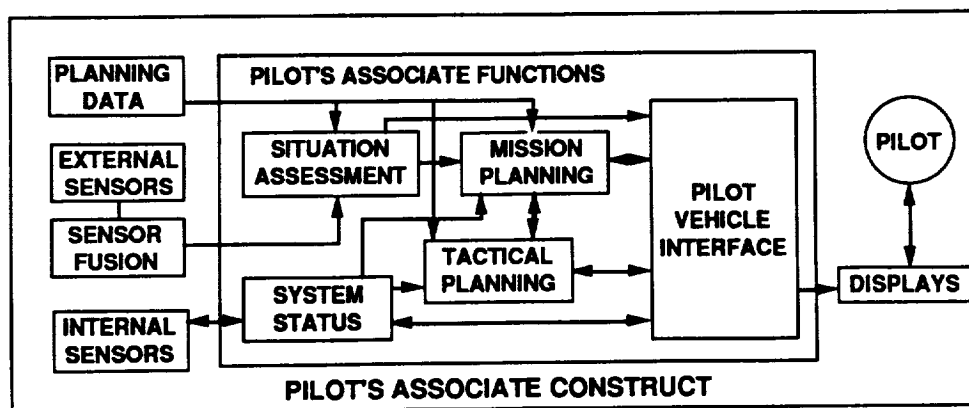


Figure 24 Pilot's Associate Functional Block Diagram

6.2.2 INTEGRATED CONTROL AND AVIONICS FOR AIR SUPERIORITY (ICAAS) PROGRAM

The ICAAS program was conceived by the Air Force to dramatically improve tactical aircraft air-to-air combat capability through the use of automation, improved on-board data analysis and improved human factors. Automated expert systems are to be developed for tactical planning, tactic selection and weapon selection. Emphasis is placed on multi aircraft and multi weapon scenarios. Emphasis is placed on beyond-visual-range encounters, but with graceful transition to within-visual-range encounters. The design assumes many enemy aircraft vs. few friendly aircraft. The program includes both domed pilot-in-the-loop simulation and flight demonstrations. The ICAAS system functional architecture is shown in Figure 25.

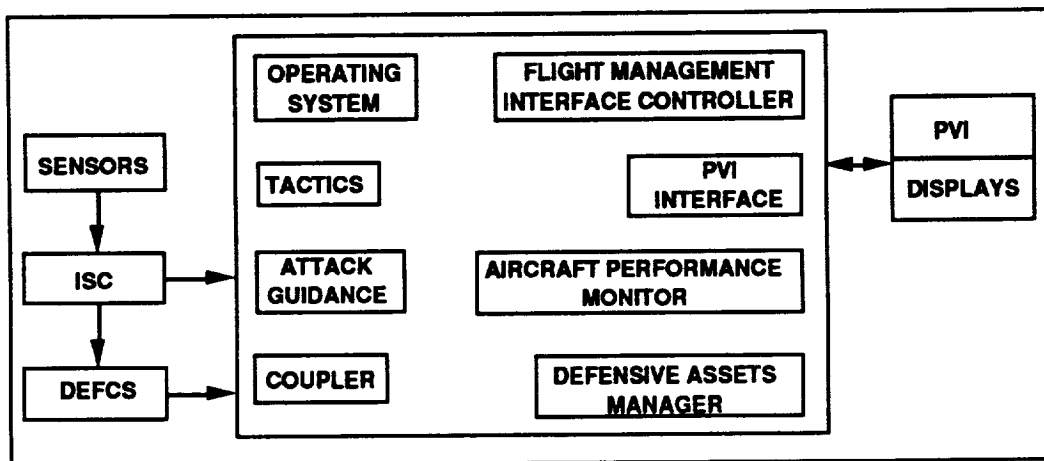


Figure 25 ICAAS System Functional Architecture

This program does not integrate readily with the proposed NASA initiative. The tasks to be automated in ICAAS are very high level tactical planning, tactics selection and weapons selection tasks for air-to-air combat. These tasks are done by manned flight leaders in IRMA applications. Thus, as with the Pilot's Associate, the state of AI technology related to expert and knowledge based systems required to support ICAAS is more advanced than is required to support IRMA.

6.2.3 ADVANCED FIGHTER TECHNOLOGY INTEGRATOR (AFTI) PROGRAM

The AFTI program is actually composed of many R&D programs, each aimed at demonstrating a technology on a specifically configured/modified aircraft. None of the technology demonstrations have any bearing on the NASA automation initiative with the notable exception of the latest AFTI program - The AFTI/F-16 Close Air Support (CAS) Program.

The AFTI/F-16 CAS program includes the following developments which would bear heavily on the NASA automation initiative:

1. Automated Terrain Following
2. Inflight Route Replanner
3. Auto Target Acquisition and Classification
4. Voice
5. Automatic Maneuvering Attack System
6. Radar - Map Correlation
7. Terrain Avoidance
8. Ground Collision Avoidance

6.2.4 INTEGRATED TACTICAL AIRCRAFT CONTROL (ITAC) PROGRAM

ITAC is a proposed program at WRDC which is not funded at the present time. The concept is very similar to the proposed NASA automation initiative: manned weapon systems internettted with UAVs. The program has been formulated and funding is being sought to support it.

The drivers for the proposed ITAC program as formulated by Jim Ramage, the WRDC engineer/manager who is constructing the program, are:

1. Survivability in a high threat environment
2. Decreasing DoD budgets resulting in fewer fighters and cuts in manpower

The survivability of human flight crews in air-to-air and air-to-ground combat has been decreasing as weapon systems continue to improve. DoD budgets are also decreasing resulting in the procurement of less and less tactical aircraft per year and cuts in manpower. An increase in fighter force multiplication is a must in WRDC's view.

WRDC projects the following capability improvements with ITAC:

1. Improved target kill capability
2. Improved survivability
3. Affordability

The potential missions envisioned by WRDC for ITAC development and employment are:

1. Electronic Countermeasures
2. Offensive Counter Air
3. Close Air Support
4. Strike

ITAC force mixes envisioned are fighters plus UAVs, C130s plus UAVs and AWACS plus UAVs. UAV employment options are:

1. Recoverable/nonrecoverable
2. Ground launch/air launch
3. Air refuelable/not air refuelable
4. Internetted UAVs/autonomous UAVs/remotely piloted UAVs

The scenario for both the air-to-air and air-to-ground ITAC concepts is one of utilizing standoff to achieve survivability for the manned command airplanes. The UAVs "mix it up" and deliver the weapons. The manned aircraft standoff from the fight, command the UAVs via internetted data link and observe the results, making adjustments in battle orders where necessary. The ITAC "continuous standoff" concept is depicted in Figure 26. We at G&C believe that while this "continuous standoff" idea is creditable, there are other internetted concepts ("assign and leave" for example) which are at least as appealing and should be researched. The interdiction concept proposed in IRMA does not use standoff. The manned command/lead aircraft flies directly over an enemy column at between 50-200 feet AGL. Survivability of the manned leader is achieved primarily by surprise instead of standoff. The low level UAV trailers are quickly assigned targets via internetted. They attack their assigned targets autonomously seconds after the leader has passed. Their exposure is greater because the enemy has had time to bring his defenses to bear. Each attack consists of one pass: the formation then continues on its way to attack another column (Figure 8). For the interdiction mission, we consider this concept superior in survivability and in effectiveness to the ITAC standoff concept

primarily because standoff connotes that you know where all the enemy's air defenses are. What about the soldier with the STINGER type missile that happens to be located on the ground in the area in which the manned leader is "standing off"? The IRMA concept is superior because it depends on surprise. Surprise is the dominating factor in determining outcomes in skirmishes/battles/war and many other competitive activities.

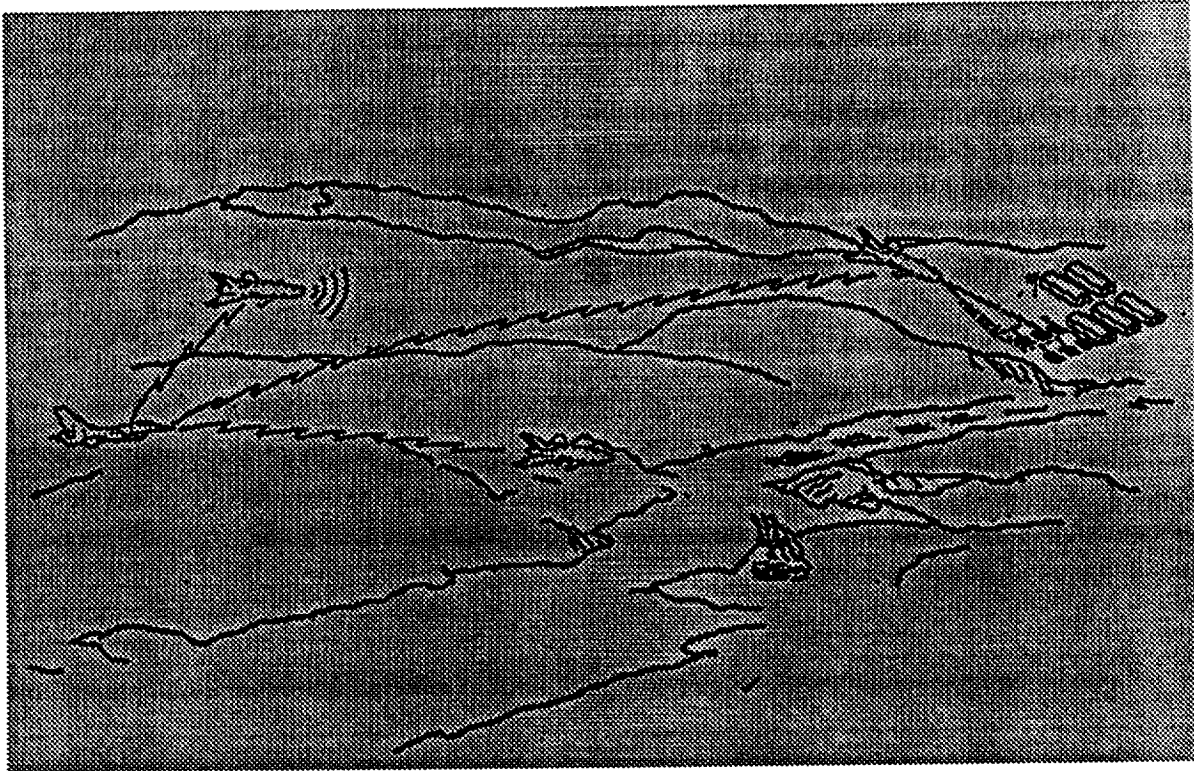


Figure 26 ITAC Strike Concept

6.2.5 INTELLIGENT AIR ATTACK SYSTEM (IAAS) PROGRAM

IAAS is an NWC China Lake initiative which has progressed with modest funding to a simulation demonstration. The system features automated navigation aids, display management, situational awareness aids, BVR decision aiding and automated assistance in mission modification. It is an AI based system with heavy emphasis on the pilot system interface.

Extensive operational pilot input was obtained on the IAAS system concepts by allowing pilots to fly the simulation as the system was developed. As a result the final demonstration system design was heavily influenced by pilot comments. What emerged was a very specific design philosophy for incorporating automation and AI based pilot aids into tactical aircraft. We

believe that this modest program contributes significantly to automation technology for tactical aircraft; specifically, it represents a design concept which was heavily operator influenced as opposed to totally engineer driven.

6.3 Technology Development Program

In Appendix D we have summarized all of the technologies which are involved in the IRMA applications discussed in this report. The tables present each technology, its development status, a list of activities/facilities who are pursuing the technology and whether or not NASA should be pursuing development in the technology. In this last category we indicate whether NASA should pursue the technology to a simulation or flight demonstration. We suggest that a technology development program be formulated under this new NASA automation initiative which focuses on two areas described in the tables:

1. Expert Systems for Airborne Applications
2. Guidance & Control, and Expert System Integration

To focus this technology development program we suggest that a specific set of scenarios be developed. We suggest that these scenarios be presented to a review panel of experts from industry and government for their comments and suggestions. In the following section we present three candidate scenarios.

6.3.1 SCENARIO DEFINITIONS FOR TECHNOLOGY DEVELOPMENT

Three scenarios are presented in this section upon which to base technology development and flight demonstration programs. The rationale used for the development of each scenario are:

1. There must be a unique aspect to the scenario which no other agency is pursuing.
2. The scenario must be supportable by the appropriate government agency.
3. The technology development required must support incremental flight demonstrations.

IRMA Interdiction

In this scenario interdiction is accomplished by a formation of aircraft flying continuously at low altitude (50-200 feet AGL) over a theater area. The lead aircraft is manned. UAVs trail the leader. The manned aircraft serves as the target identifier and designator and the UAVs act as the trailing attackers. The concept is shown in Figure 27.

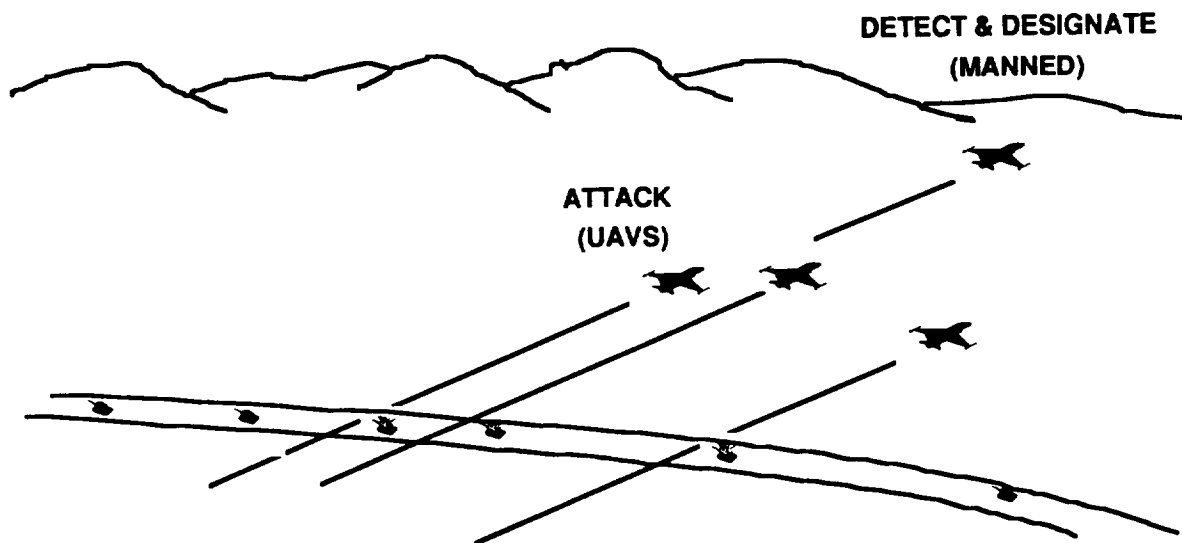


Figure 27 IRMA Interdiction Scenario (InMASS)

The entire formation operates below 200 feet. The lead (manned) aircraft makes one pass over the target area. He is gone before the enemy can react. Targets are designated and assigned to unmanned trailers by the lead aircraft via high capacity/high speed internetted data link. These highly maneuverable, unmanned attacking aircraft fly two to ten seconds (approximately 1000 to 5000 feet) behind their leader. They use forward firing weapons (cannon), aerodynamically braked general purpose bombs (snake-eye series Mk-82), anti-personnel cluster bombs or specially designed smart weapons to attack their targets.

In this interdiction concept, the attacking aircraft make only one low altitude pass over the interdicted column. The low altitude strike group then proceeds to attack another column and may return to previously attacked columns later in the interdiction mission. Multiple columns are attacked until the formation reaches a bingo fuel state (time to go home) or exhausts its weapons. Several of these formations may be roaming a battle theater simultaneously. Coordination between groups and track adjustments would be made through JTIDS type communications with a command center. The concept applied on a theater level against an attacking army moving in columns along available transportation corridors is depicted in Figure 28.

This interdiction IRMA scenario and concept are not being pursued in WRDC's ITAC program. ITAC concentrates exclusively on scenarios which use "continuous standoff" as the method of reducing risk to the manned aircraft. The proposed scenario uses the concept of "assign and leave". The concept was first developed at Northrop Corporation and later at SPARTA, Incorporated by Mr. Hershel Melton in a Phase I SBIR sponsored by WRDC. The concept was known as InMASS (Internetted Multiple Aircraft Surface Strike).

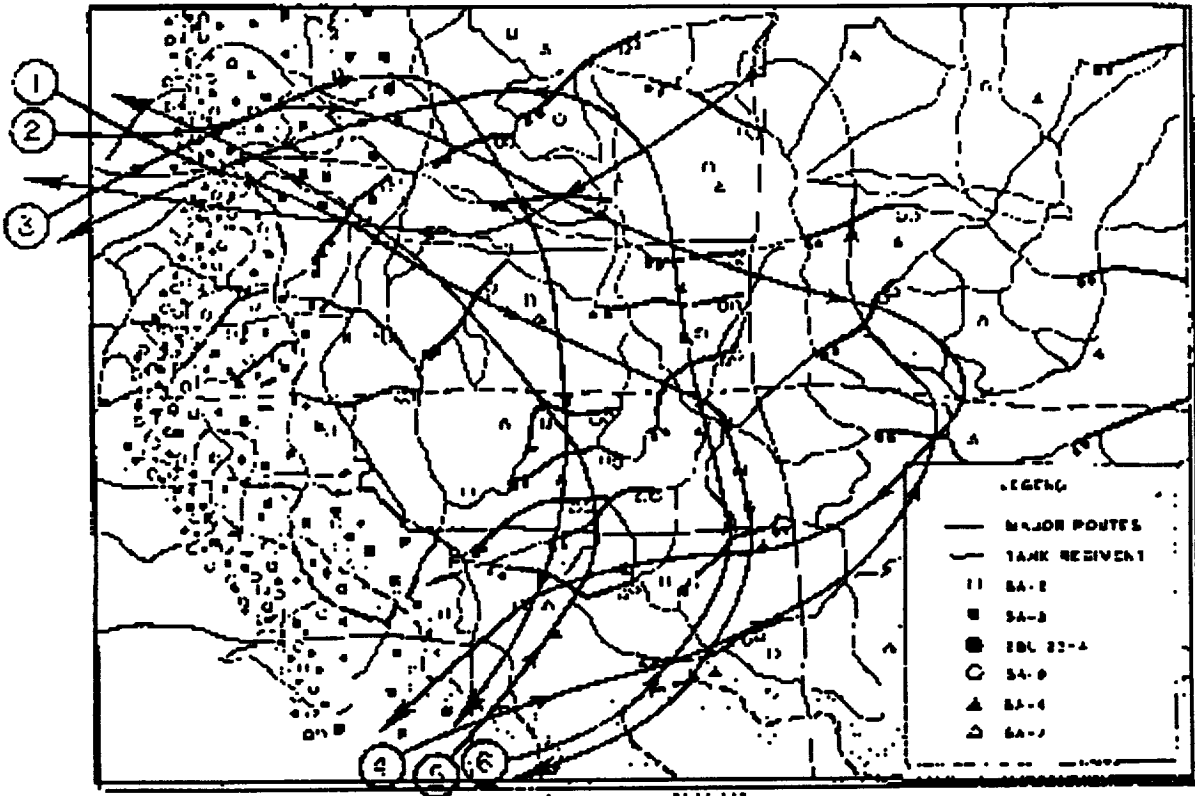


Figure 28 The Interdiction IRMA Scenario on the Theater Level (InMASS)

The technologies which require development to support demonstrations of this scenario are:

1. Automated formation flying (station keeping)
2. Automated maneuvering (weapons delivery)
3. Internetted communication
4. Automated rendezvous
5. Terrain avoidance
6. Collision avoidance
7. Target designation
8. Trajectory generation
9. Weapons definition
10. System launch and recovery

IRMA Forest Fire Fighting

In this scenario UAVs are employed as tanker aircraft being controlled by airborne flight controllers in orbiting coordination aircraft. The concept is shown in Figure 29 below.

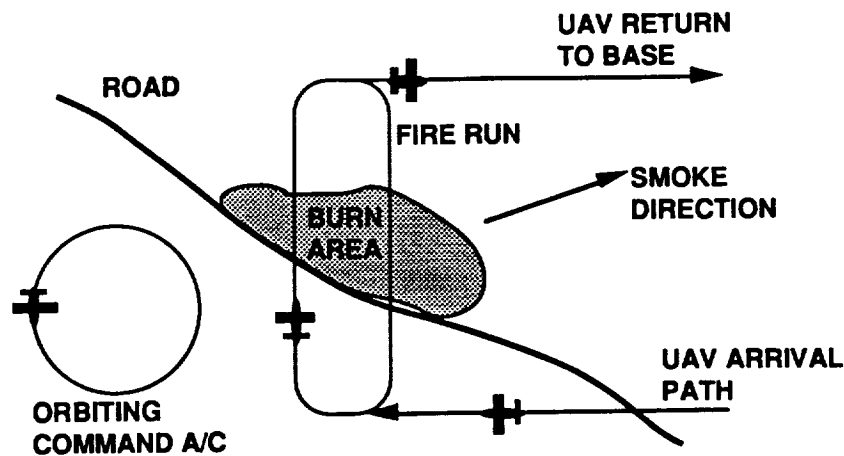


Figure 29 IRMA Forest Fire Fighting Scenario

The unmanned aircraft would be rather large tanker aircraft containing a significant level of machine intelligence on-board and controlled in the same manner as automated wingmen in the tactical applications. That is: high level commands are issued to the unmanned tanker via UHF or VHF voice radio. Responses and other data are transmitted back to the controller aircraft via internetted data link. Technologies required are expert systems and natural language understanding.

The technologies which require development to support demonstrations of this scenario are:

1. Automated maneuvering
2. Internetted communication
3. Automated rendezvous
4. Terrain avoidance
5. Collision avoidance
6. Natural language understanding
7. Trajectory generation
8. System launch and recovery

It is possible to envision a system which does not require natural language understanding of voice communication as an interim first system for this application. Unmanned tankers could be controlled at a lower level by pilots in manned aircraft flying a detached wing position on the

tanker. The controller aircraft would be small general aviation aircraft with sufficient performance to fly wing on the tanker being controlled. The controller could avoid the very low level fire and smoke environment which the tanker would fly through. This type of control has been used by the military for years with expensive, large target drones. This forest fire fighting concept is depicted in Figure 30 below.



Figure 30 Alternate IRMA Forest Fire Fighting Scenario

The technologies which require development to support demonstrations of this scenario are the same as those listed for the first forest fire fighting scenario with the exception of item 6.

IRMAHAARP

This scenario has not been developed as of this writing. It was suggested at the review at NASA Langley.

6.3.2 DIVISION OF RESPONSIBILITIES

A three phase program is suggested for the selected program (scenario). Phase I would involve technology developments at multiple centers and/or facilities. Phase II would involve an integration of the developed technologies at one center or facility. Phase III would feature a flight demonstration at NASA Ames-Dryden. There would be multiple Phase IIs and Phase IIIs. The concept is shown in Figures 31 and 32.

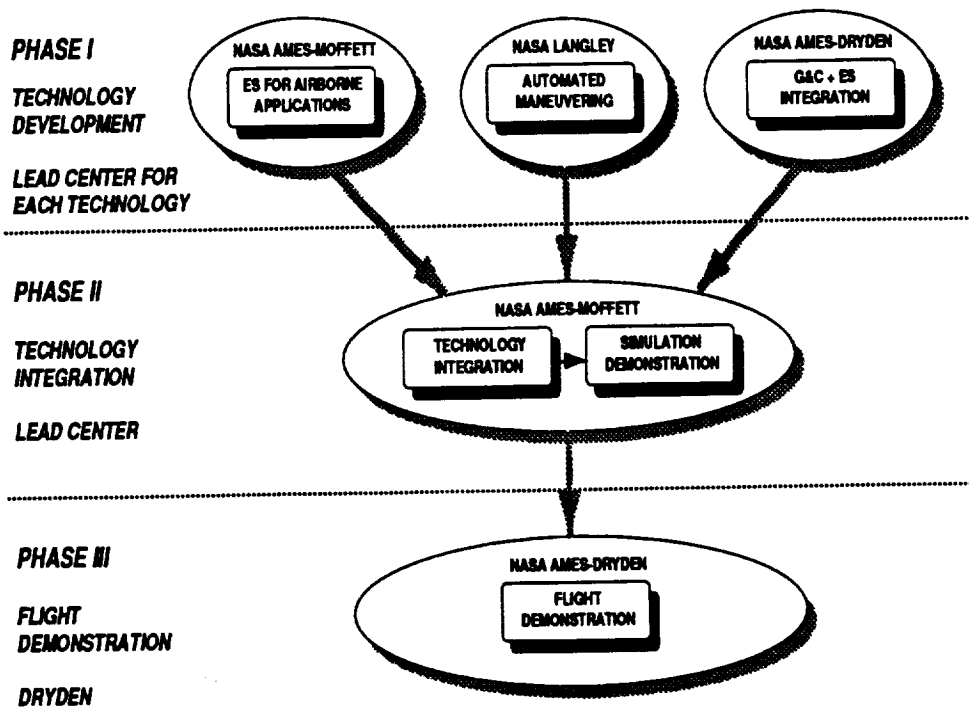


Figure 31 Program Example

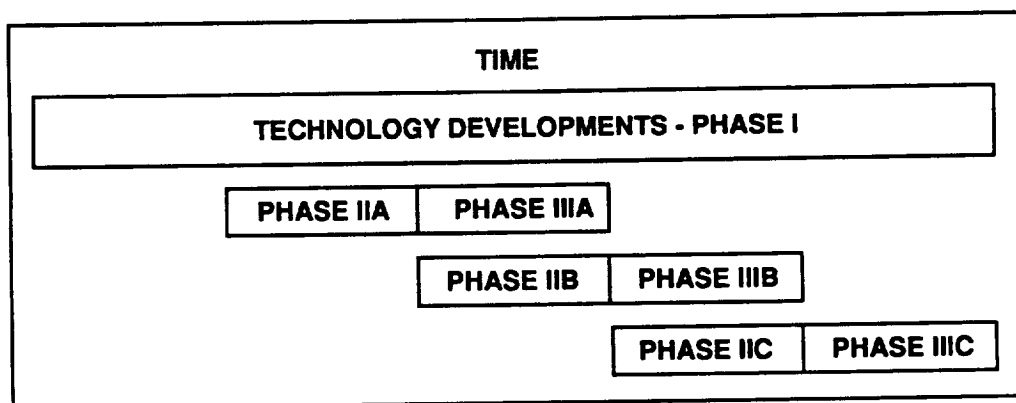


Figure 32 Multiple Phase IIs and IIIs

Phase I would extend for nearly the duration of the multi-year program. A Phase II would be commenced when a set of technologies was mature enough to support a flight demonstration. A Phase III would support the flight demonstration. Demonstrations would be scheduled nominally on a yearly basis with a new Phase II and III commencing each year.

6.4 Flight Demonstration Program

Multiple flight demonstrations (Phase IIIs) would be conducted during the span of the program. These incremental demonstrations would be conducted at NASA Ames-Dryden using F-18 flight test aircraft for both manned aircraft and UAV flying simulators. Pilots in the UAV simulators would act as safety pilots during the demonstrations. Takeoffs, climbouts, approaches and landings would not be demonstrated as UAV maneuvers: that is, the F-18 safety pilot would perform all these maneuvers.

Flying demonstrations would be conducted using remote computation to support high throughput expert system and trajectory generation programs which could not be supported by on-board computers. The transputer based Flight Research Computer now under development in a Phase II SBIR at NASA Ames-Dryden would be used in the demonstrations for on-board computation, however, this computer would undoubtedly have to be extensively augmented by remote computation.

Internetting could also be simulated through the use of tracking RADAR, telemetry and remote computation, however, we strongly recommend that an actual millimeter-wave data link be developed and installed in the demonstration F-18s so that the internetting concept could actually be demonstrated. The transputer based Flight Research Computers could support this function. Millimeter-wave hardware is very small and inexpensive, and includes transmitters, receivers and antennas. A small Orange County based company builds the hardware and has supported a previous flight demonstration of internetting using general aviation airplanes at Flight Systems, Mojave. A millimeter-wave link is suggested because it allows for covert operations and automated formation flying: The range of millimeter-wave transmissions for a given power output at the antenna can be precisely controlled by controlling the transmission frequency. In addition, directivity is easily attained: the system lends itself to being used for precise range and bearing measurements (to another airplane) for automated formation flying algorithm inputs.

In an internetting demonstration, the Flight Research Computer would support prefiltering of range and bearing data and transmission of it to the remote computation facility where a guidance loop closure for a UAV (F-18) keeping station on a manned leader would be performed. Finally, control commands would be uplinked to the UAV. The concept is shown in Figure 33.

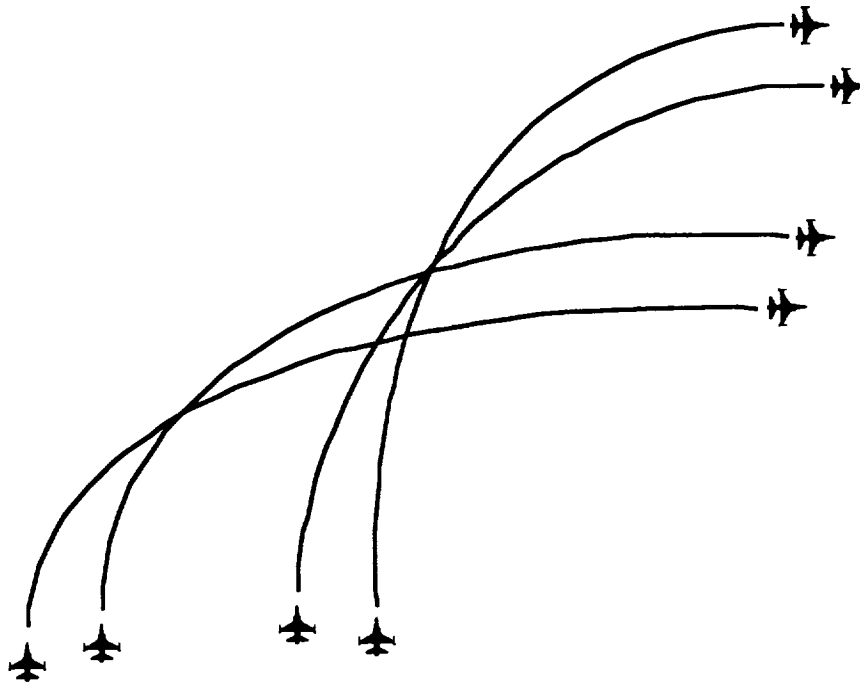


Figure 33 Formation Flying Demonstration Using Internetted Data Link

A Representative series of flight demonstrations for a typical IRMA application is given below:

1. Demonstration of internetted communication.
2. Demonstration of formation flying using internetting.
3. Demonstration of a limited IRMA application task.

7.0 RECOMMENDATIONS AND CONCLUSIONS

This study is not complete. Further sponsorship is recommended to:

1. focus the proposed initiative on a specific scenario (possibly one of the three described herein),
2. form a review panel to aid in the definition of the proposed program,
3. orchestrate the review panel's activities and
4. support the program's advocacy.

In addition, support should be sought from other government agencies including WRDC, DARPA and the DoD Autonomous Vehicle Office.

8.0 REFERENCES

1. "U.S. Anti-Drug Operations," *Aviation Week*, January 30, 1989, vol. 130, no. 5, pp. 34-53.
2. Franklin, J. and Karna, K., "Shaping Knowledge Within Artifacts," *IEEE Expert*, Spring 1989, vol. 4, no.1, pp. 3-5.
3. Franklin, J.E.; Carmody, C.L.; Keller, K.; Levitt, T.S.; and Buteau, B.L., October 1988, "Expert System Technology for the Military: Selected Samples," *Proceedings of the IEEE*, pp. 1327-1366.
4. Loatman, R.B. and Post, S.D., September 1988, "A Natural Language Processing System for Intelligence Message Analysis," *SIGNAL Magazine*.
5. Loatman, R.B. and McCown, M.G., October 1987, "Information Extraction from Natural Language Messages," *Proceedings of ESIG*.
6. Shumaker, R.P. and Franklin, J., June 1986, "Artificial Intelligence in Military Applications," *SIGNAL Magazine*.
7. Youngers, M.; Franklin, J.; Carmody, C.L.; and Meyrowitz, A., June 1986, "Improving C3: The Potential of Artificial Intelligence," *SIGNAL Magazine*, pp. 51-55.
8. "Manufacturers Unveil Models of New Remotely Piloted Vehicles," *Aviation Week*, July 3, 1989, vol. 131, no. 1, pp. 48-52.
9. Hewett, M.D. and Tartt, D.M., "The Development of a Flight Test Engineer's Workstation for the Automated Flight Test management System," 20th Annual Society of Flight Test Engineers Symposium, Reno, Sept. 1989.

APPENDIX A RESULTS OF THE NASA AMES-MOFFET AND HEADQUARTERS REVIEWS

The advocacy briefing (Appendix C) was presented on 4 January to Mr. Douglas Arbuckle at NASA Headquarters. His comments are summarized below:

Mr. Arbuckle preferred to refer to the potential civil applications as “spin-off” applications of technology developed for the military applications. He suggested that the military applications be emphasized and that the technology development focus specifically on applications for tactical military aircraft. Mr. Arbuckle was supportive of the basic concepts presented. Mr. Arbuckle suggested that the briefing emphasize that the proposed initiative represents a natural continuation of past and present work supported by NASA as opposed to a change in direction or emphasis. Mr. Arbuckle planned to brief Mr. Jeremiah Creedon on the initiative on 18 January.

The advocacy briefing (Appendix A) was presented on 18 January to the following personnel at NASA Ames-Moffett by Dr. Hewett and Mr. Duke.

Dr. Henry Lum
Mr. Gregory Condon
Mr. Dallas Denery

Their comments are summarized below:

Dr. Lum

Dr. Lum was generally supportive. He felt that the concepts proposed were appropriate applications of AI technology and that flight demonstrations were possible as described. He pointed out that the California Forestry Service was very open to innovative ideas of the type presented herein for automated forest fighting. Dr. Lum agreed to review the Advanced Technology Status charts (4 charts) in detail and correct them where appropriate.

Mr. Condon and Mr. Denery

Mr. Condon's and Mr. Denery's comments were offered essentially in unison. They felt that the proposed initiative was too broad and required considerable narrowing of scope. They suggested that the way to narrow the scope of the initiative was to define and focus on a very specific scenario. They agreed that this scenario should be in the tactical military aircraft arena. They supported the basic automation concepts proposed and suggested that a scenario could be defined from one of the proposed military

applications. They suggested that the chosen area for technical development to be pursued under the initiative by NASA should be an area that not only requires development, but also one that is not being worked adequately by other agencies. They declared that the definition of a specific scenario and the decision to work in an area largely neglected by others were two of the main reasons that they were successful in advocating and obtaining funding for their Helicopter Automated Nap-of-the-Earth Flight Program.

Mr. Condon and Mr. Denery made a second major point. They strongly suggested that a panel of experts be formed to review the proposed initiative, help define the specific scenario and help select the specific area for technical development and flight demonstration. They suggested that this panel be composed of specific individuals from DoD laboratories and R&D field activities, the aerospace industry, NASA centers and headquarters. They suggested that this committee meet two or three times to review progress on the development of the initiative. They claimed that this tool worked well for them in defining the Automated Nap-of-the-Earth Flight Program.

Mr. Condon felt that the drug interdiction application was not supportable because it did not involve scenarios where the unmanned vehicles were specifically used to remove human crews from high risk environments. His position was that the only supportable argument for the use of unmanned vehicles in any application was to reduce the risk of loss of human life.

APPENDIX B RESULTS OF THE NASA LANGLEY REVIEW

The advocacy briefing (Appendix C) was presented on 13 February to Mr. Jerryl Elliott (NASA Langley), Mr. Raymond Hood (NASA Headquarters), Mr. James Ramage (WRDC), and Mr. Douglas Arbuckle (NASA Headquarters).

Dr. Hewett (G&C Systems) presented the advocacy briefing. Mr. Ramage presented a briefing on the ITAC program. Mr. Ramage was concerned that the planned NASA new initiative could endanger his program (ITAC): that is, the government might not support two programs so closely aligned. The group discussed cooperative efforts, however, no definitive conclusions were reached. It is G&C's belief that the automation in initiative can be properly focused so as not to compete with but to add to the ITAC program.

Mr. Elliott expressed his view that the new initiative required much more focus before it could be advocated.

APPENDIX C ADVOCACY BRIEFING

NASA

AUTONOMOUS AIRCRAFT INITIATIVE

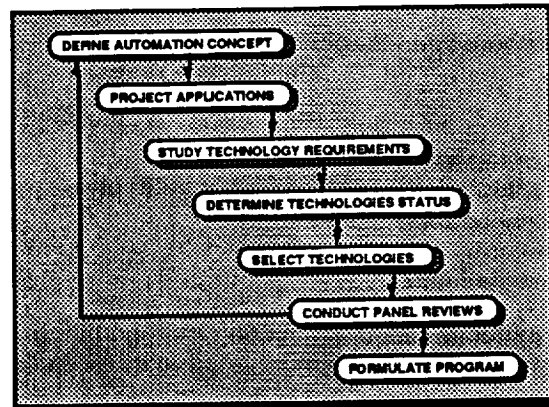
A NEW NASA INITIATIVE IN AUTOMATION FOR THE 90'S

NASA AMES DRYDEN FLIGHT RESEARCH FACILITY
EDWARDS, CA

APPENDIX C ADVOCACY BRIEFING

NASA

PROGRAM DEFINITION PROCESS



NASA

AUTONOMOUS AIRCRAFT INITIATIVE DEFINITION PROCESS

DEFINE AUTOMATION CONCEPT

- ◆ Must have excellent payoffs in military applications and spinoffs in civil applications
- ◆ Must require the coordinated efforts of more than one NASA center
- ◆ Must be supported by other government agencies
- ◆ Must involve the integration of technologies which NASA has promoted and been involved in the development of

APPENDIX C ADVOCACY BRIEFING

NASA

AUTONOMOUS AIRCRAFT INITIATIVE DEFINITION PROCESS (cont'd)

PROJECT APPLICATIONS OF THE CONCEPT

- ◆ Military
- ◆ Civil

STUDY TECHNOLOGY REQUIREMENTS

DETERMINE THE DEVELOPMENT STATUS OF THE REQUIRED TECHNOLOGIES

- ◆ US government sponsored developments
- ◆ IRAD Programs
- ◆ Foreign developments

SELECT TECHNOLOGIES FOR NASA DEVELOPMENT

FORMULATE A TECHNOLOGY DEVELOPMENT AND DEMONSTRATION PROGRAM

- ◆ Technology development
- ◆ Demonstration (simulation or flight)

NASA

AUTONOMOUS AIRCRAFT INITIATIVE PROGRAM CONCEPT

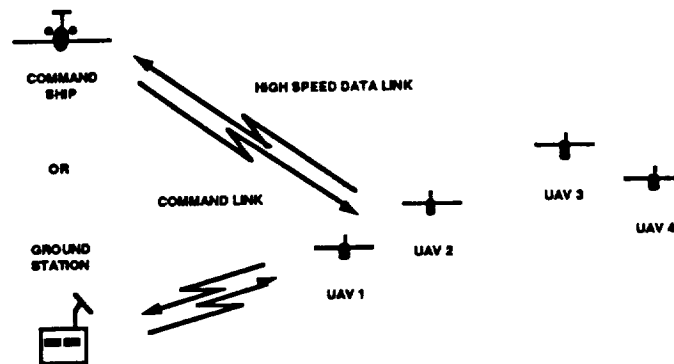
CONCEPT DEFINITION

- ◆ Unmanned robotic airplanes supervised via data link by human controllers in manned airplanes or ground stations
- ◆ Inter airplane/controller communication consists of low bandwidth command links from the controller to the unmanned airplanes and high bandwidth data links from the unmanned airplanes to the controller
- ◆ Unmanned airplanes may operate in close proximity to manned airplanes
- ◆ Unmanned airplanes are equipped with multiple sensors and intelligent systems
- ◆ Unmanned airplanes are capable of supporting a successful recovery in the event of communications loss with the controller

APPENDIX C ADVOCACY BRIEFING

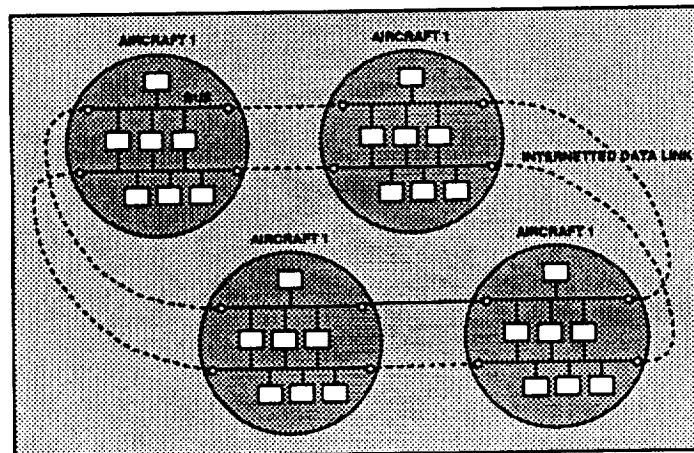
NASA

INTERNETTED ROBOTIC AND MANNED AIRCRAFT SYSTEM (IRMA) CONCEPT DEFINITION



NASA

INTERNETTED AVIONICS EXTENSIONS THROUGH IRMA



APPENDIX C ADVOCACY BRIEFING

NASA

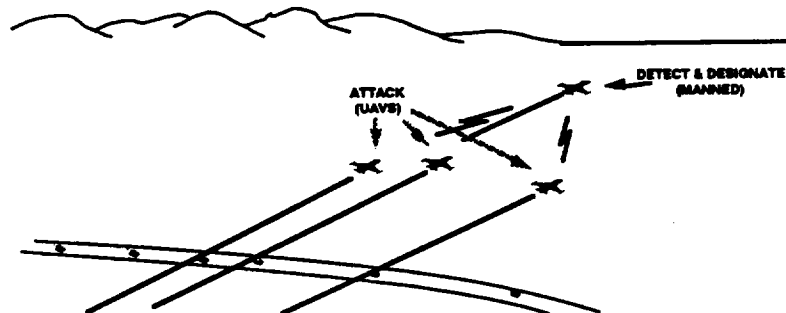
AUTONOMOUS AIRCRAFT INITIATIVE PROGRAM APPLICATIONS

POTENTIAL MILITARY APPLICATIONS

AIR INTERDICTION	The prevention by air power of ground movement of enemy forces or supplies
STRIKE	Air-to-ground attack of prebriefed targets
RECONNAISSANCE	Aerial survey of enemy held territory
FIGHTER SWEEP	Flight over enemy held territory for the purpose of eliminating flying enemy counter air
INTERCEPT	Elimination by air of a specific enemy offensive air penetration of friendly air space
COMBAT AIR PATROL	Flying patrol assigned to defend specific airspace from enemy air penetration
COUNTER AIR	Air defense of friendly airspace or territory

NASA

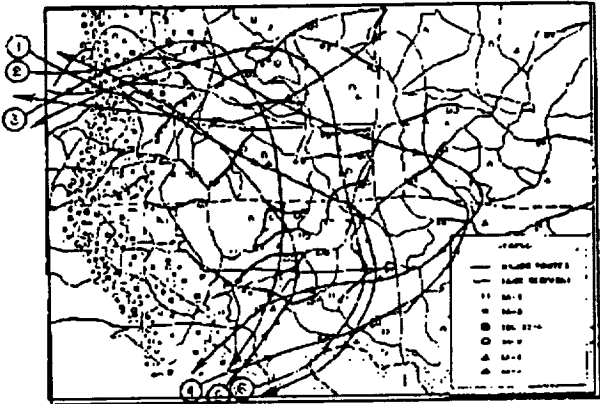
AIR INTERDICTION EXAMPLE (InMASS)



APPENDIX C ADVOCACY BRIEFING

NASA

THE INTERDICTION MARS CONCEPT ON THE THEATER LEVEL
(InMASS)



NASA

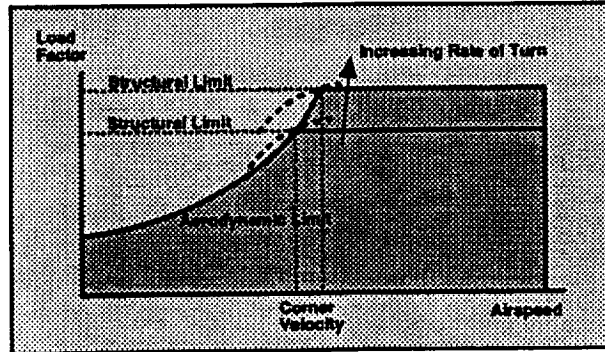
ITAC STRIKE SCENARIO



APPENDIX C ADVOCACY BRIEFING

NASA

TURNING PERFORMANCE LIMITATIONS



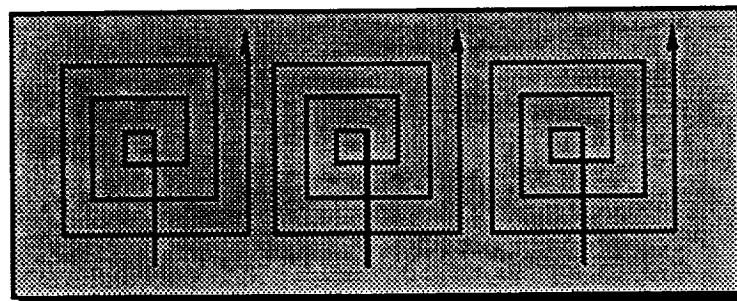
POINT - Higher structural limit means:

1. Higher rate of turn
2. Lower radius of turn

At higher corner velocity

NASA

SEARCH AND RESCUE PATTERNS FLOWN BY MULTIPLE UAVs



APPENDIX C ADVOCACY BRIEFING

NASA

MANNED AIRCRAFT vs. UAV 5 YEAR COST COMPARISON

Expense Item	Time	Configuration A	Configuration B
FLIGHT TRAINING	1 1/2 years	\$400 K	\$1,800 K
AMORTIZED AIRCRAFT PROCUREMENT	1 1/2 years	\$12,500 K	\$20,000 K
FLIGHT CREW SUPPORT	5 years	\$1,500 K	\$6,000 K
AIRCRAFT OPERATING EXPENSES	3 1/2 years		
Maintenance Support		\$1,400 K	\$1,700 K
Fuel		\$2,300 K	\$3,100 K
TOTAL AMORTIZED EXPENSES		\$18,100 K	\$32,400 K

GROUND RULES:

CONFIGURATION A
1 manned A/C - 3 UAVs

CONFIGURATION B
4 manned A/C

1. FLIGHT TRAINING - 18 months
2. AVERAGE FLIGHT CREW TIME OF SERVICE - 5 years
3. FLIGHT CREW AVERAGE SALARIES - \$50K/yr (overhead multiplier - 3.0)
4. MMH/FH - 10 for manned A/C, 8 for UAV
5. AVERAGE FLIGHT HOURS PER YEAR PER A/C - 200
6. SUPPORT CREW AVERAGE SALARIES - \$40K /yr (3.0 multiplier)
7. FUEL COST - \$1 per gallon
8. AVERAGE FUEL CONSUMPTION - 7,500 lbs/hr for manned A/C, 5000 lbs/hr for UAV

NASA

AUTONOMOUS AIRCRAFT INITIATIVE PROGRAM APPLICATIONS (cont'd)

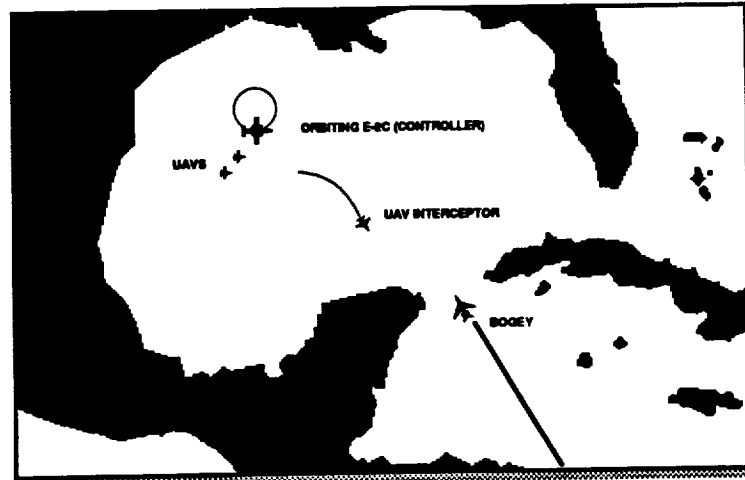
POTENTIAL CIVIL APPLICATIONS

HIGH ALTITUDE ATMOSPHERIC SAMPLING	Long duration autonomous operations in severe climate conditions and remote locations
DRUG INTERDICTION	The identification, interception, tracking and apprehension of aircraft, water craft, ground vehicles and personnel smuggling drugs into the US
BORDER SURVEILLANCE	Continuous (in time and space) air surveillance operations over US borders to identify potential air, water or ground drug smugglers penetrating borders
SEARCH AND RESCUE	The coordinated search for downed or presumed downed aircraft, disabled or sunk water craft, survivors and their subsequent rescue by aircraft and/or water craft
FOREST FIRE FIGHTING	The coordinated air attack of forest fires by specifically equipped aircraft and crews employed by the forest service or by civilian contractors
COMMERCIAL LOGGING	The transportation of logs by dual helicopter systems with precision forest extraction and downloading

APPENDIX C ADVOCACY BRIEFING

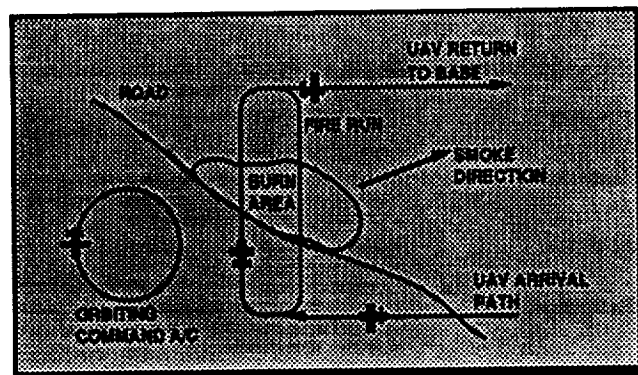
NASA

DRUG INTERDICTION EXAMPLE



NASA

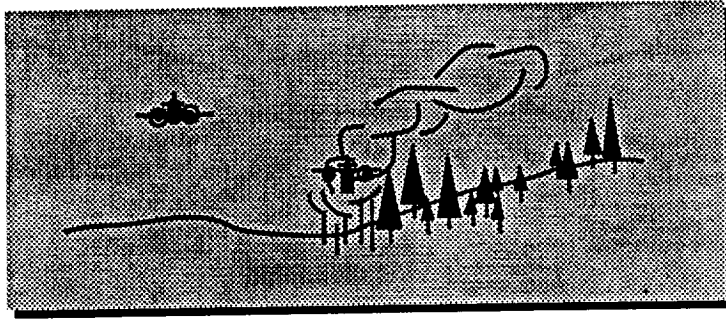
FOREST FIRE FIGHTING APPLICATION



APPENDIX C ADVOCACY BRIEFING

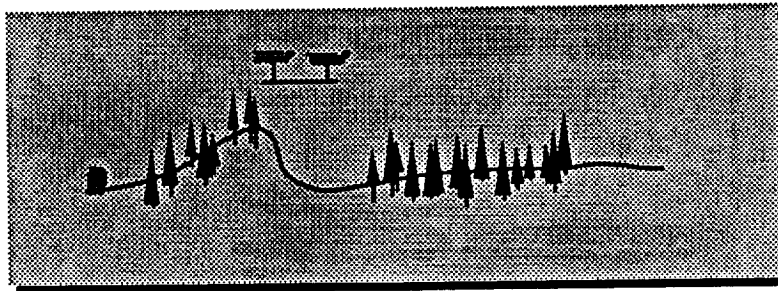
NASA

ALTERNATE FOREST FIRE FIGHTING CONCEPT

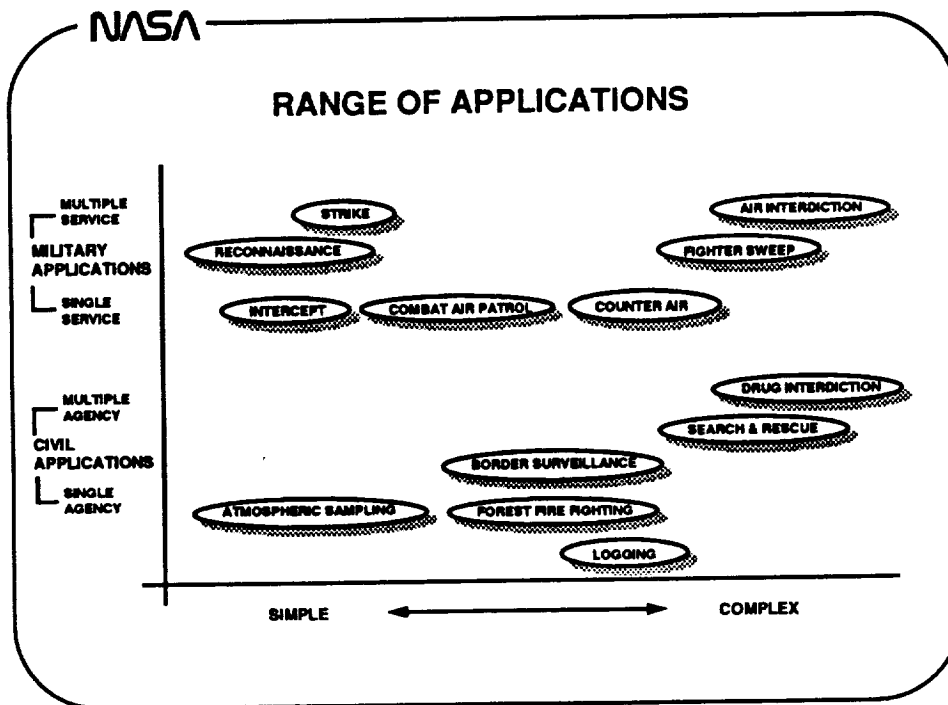
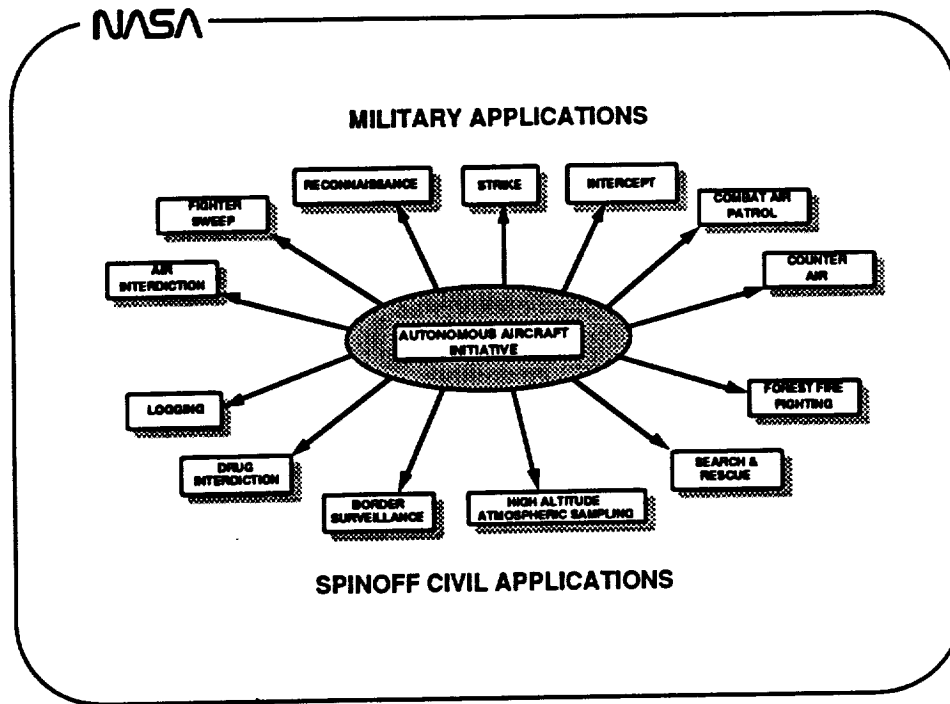


NASA

IRMA LOGGING CONCEPT



APPENDIX C ADVOCACY BRIEFING



APPENDIX C ADVOCACY BRIEFING

NASA

AUTONOMOUS AIRCRAFT INITIATIVE PROGRAM

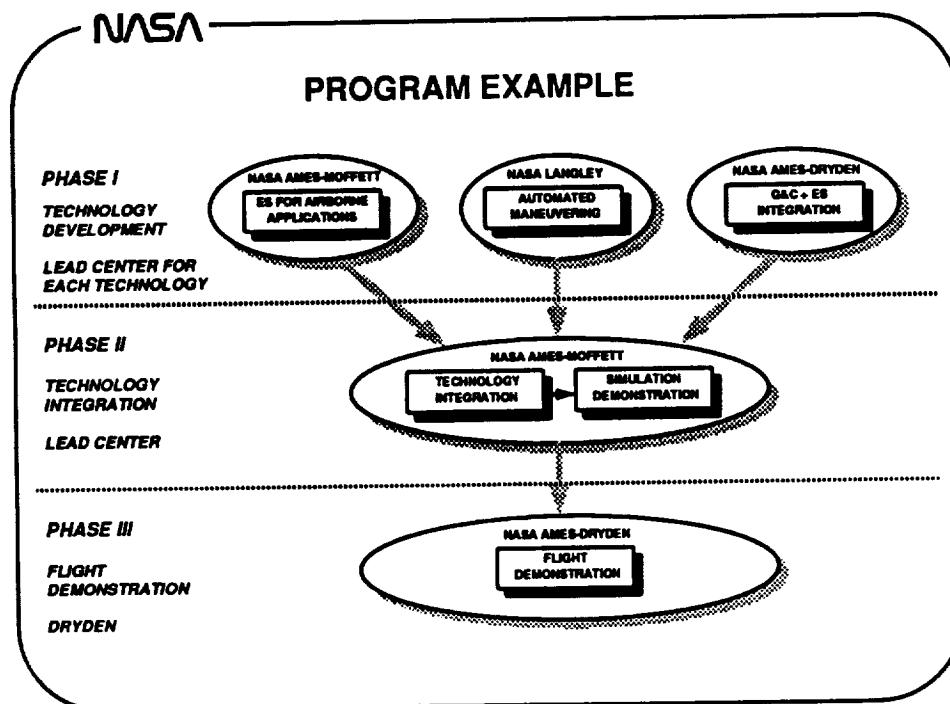
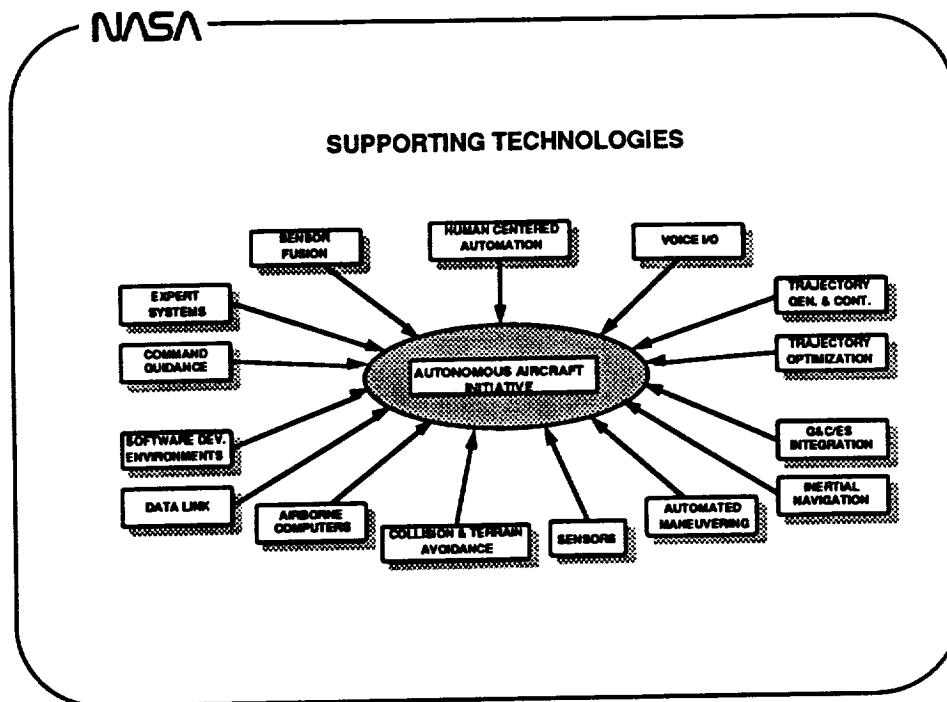
- ◆ A multi-centered program with NASA Ames Research Center - Dryden Flight Research Facility taking the lead
- ◆ Program focuses on two concepts which the USAF is beginning to develop strong interest in
 - ◆ Internetted aircraft
 - ◆ Smart UAV's operating in close proximity to and highly coordinated with manned aircraft
- ◆ Concept has civil spinoffs particularly related to the war on drugs
- ◆ Program allows NASA to pursue selected technical development within the agency while also drawing on outside developments
- ◆ Program supports selected and continuous flight demonstrations of technology developments
 - ◆ Program allows early flight demonstrations of limited developments which are already in the advanced development stage

NASA

AUTONOMOUS AIRCRAFT INITIATIVE PROGRAM INVOLVES:

- ◆ Conducting research in the technologies required to support the proposed concept for both military and civil applications
- ◆ Developing research prototype IRMA systems and/or components of these systems which can be combined with existing equipments to build demonstratable prototypes
- ◆ Conducting the flight demonstrations of these prototypes

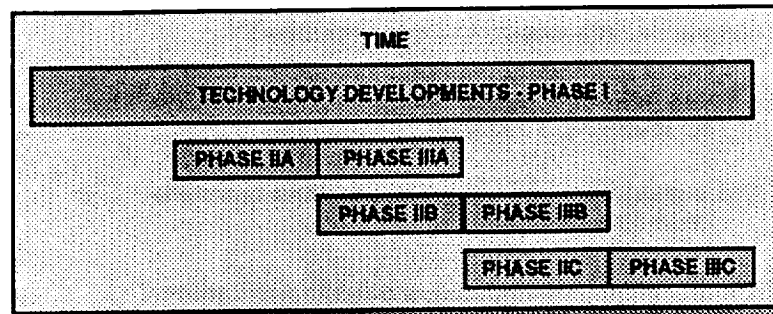
APPENDIX C ADVOCACY BRIEFING



APPENDIX C ADVOCACY BRIEFING

NASA

MULTIPLE PHASE IIs and IIIs



NASA

SUGGESTED IRMA SCENARIO DEFINITIONS FOR TECHNOLOGY DEVELOPMENT

Suggested scenarios upon which to base technology development and flight demonstration programs:

- ◆ IRMA INTERDICTION
- ◆ IRMA FOREST FIRE FIGHTING
- ◆ IRMA HAARP

APPENDIX C ADVOCACY BRIEFING

NASA

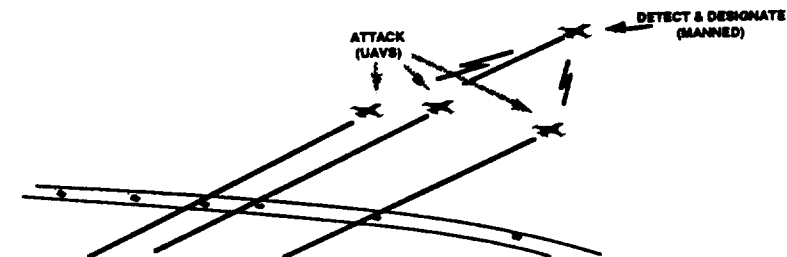
RATIONALE FOR SCENARIO DEFINITIONS

The rationale for the selection of these scenarios is:

- ◆ There must be a unique aspect to the scenario which no other agency is pursuing
- ◆ The scenario must be supportable by the appropriate government agency
- ◆ The technology development required must support incremental flight demonstrations

NASA

AIR INTERDICTION SCENARIO (InMASS)



APPENDIX C ADVOCACY BRIEFING

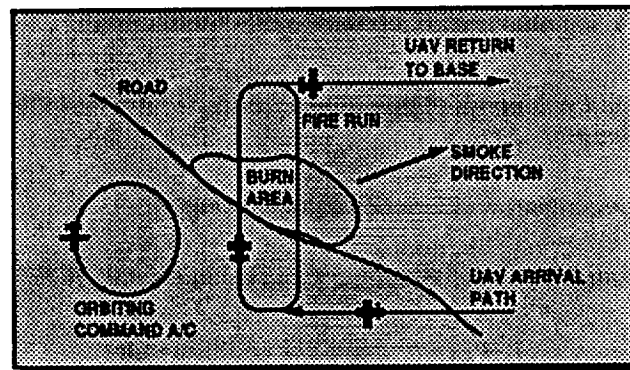
NASA

TECHNOLOGIES REQUIRING DEVELOPMENT TO SUPPORT IRMA AIR INTERDICTION

- ◆ AUTOMATED FORMATION FLYING
- ◆ INTERNETTED COMMUNICATION
- ◆ AUTOMATED RENDEZVOUS
- ◆ AUTOMATED TERRAIN AVOIDANCE
- ◆ AUTOMATED COLLISION AVOIDANCE
- ◆ AUTOMATED MANEUVERING
- ◆ TARGET DESIGNATION
- ◆ TRAJECTORY GENERATION
- ◆ WEAPONS DEFINITION
- ◆ SYSTEM LAUNCH AND RECOVERY

NASA

FOREST FIRE FIGHTING SCENARIO



APPENDIX C ADVOCACY BRIEFING

NASA

TECHNOLOGIES REQUIRING DEVELOPMENT TO SUPPORT FOREST FIRE FIGHTING

- ◆ AUTOMATED FORMATION FLYING
- ◆ INTERNETTED COMMUNICATION
- ◆ AUTOMATED TERRAIN AVOIDANCE
- ◆ AUTOMATED COLLISION AVOIDANCE
- ◆ AUTOMATED MANEUVERING
- ◆ TRAJECTORY GENERATION
- ◆ NATURAL LANGUAGE UNDERSTANDING
- ◆ SYSTEM LAUNCH AND RECOVERY

NASA

REPRESENTATIVE DEMONSTRATIONS

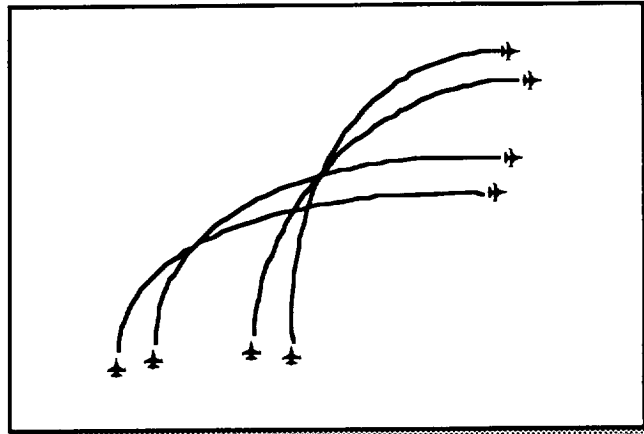
A representative series of flight demonstrations for a typical IRMA application are:

- ◆ Demonstration of internetted communication
- ◆ Demonstration of formation flying using internetted F-18s
- ◆ Demonstration of a limited IRMA application task.

APPENDIX C ADVOCACY BRIEFING

NASA

MARS FORMATION - DIVISION TURN



APPENDIX D ADVANCED TECHNOLOGY STATUS CHARTS

ADVANCED TECHNOLOGY STATUS TO SUPPORT THE AUTONOMOUS AIRCRAFT INITIATIVE PROGRAM

Advanced Technology	Requirement	Development Status*	Further development planned by ----- **	Suggested for NASA development - to SIM - to flight
Intelligent Systems				
Expert Systems (ES) for Aerospace Applications	Real-time execution of ES	SIM DEMO	USAF, DARPA, NASA	✓
	Cooperating ES	ADV DEV	USAF, DARPA, NASA	✓
	Distributed ES	THEORY	USN, IRAD, NASA	✓
	Parallel Processing of ES	EXP DEV	NASA, IRAD	✓
	Learning Systems	EXP DEV	DARPA, IRAD, NASA	
Sensor Fusion (SF)	Monitoring & diagnostic ES	SIM DEMO	ALL	✓
	ES - G&C integration	EXP DEV	NASA	✓
	Fault tolerant/gracefully degrading ES	EXP DEV	NASA	✓
	ES V&V	EXP DEV	IRAD, DARPA	✓
	Expert system for SF	EXP DEV	IRAD	✓
Voice I/O	Advanced concepts/filters/algorithms for SF of FLIR data, RADAR data, RADAR altimeter data, Navigation data, (NAVAID, map, GPS, INS)	EXP DEV	IRAD	✓
	Video data, Air data	EXP DEV	IRAD	✓
	Voice command understanding of limited vocabulary over UHF	SIM DEMO	USAF, DARPA, IRAD	✓
	Command acknowledgement over UHF	EXP DEV	DARPA	✓
	Appropriate crew-system interface	FLT DEMO	USAF, DARPA	✓
Human centered Automation	NONE	No known development	USN	US Navy
	THEORY	Research work only (academic or IRAD)	USAF	US Air Force
	EXP DEV	Exploratory development work funded	NASA	NASA National Aero. & Space Administ.
	ADV DEV	Advanced development work funded	DARPA	Defense Adv. Rsch. Projects Agency
	SIM DEMO	Demonstrated in simulation	IRAD	Aerospace Industry
* Development Status Codes	FLT DEMO	Demonstrated in flight	FGN	Foreign
	PRODUCT	Resident on a production vehicle	ALL	All of the above
** Activity codes				

APPENDIX D ADVANCED TECHNOLOGY STATUS CHARTS

ADVANCED TECHNOLOGY STATUS TO SUPPORT THE AUTONOMOUS AIRCRAFT INITIATIVE PROGRAM (cont'd - 1)

Advanced Technology	Requirement	Development Status*	Further development planned by ----- **	Suggested for NASA development - to SIM - to flight
<u>Guidance & Control</u>				
Trajectory Generation (TG) & Control	TG algorithms for Bingo	SIM DEMO	ALL	✓
	Emergency Mission related maneuvers			
	Automated path tracking			
	Automated maneuvering			
Trajectory Optimization	Optimal flight paths for Bingo	ADV DEV	ALL	✓
	Emergency Mission related maneuvers			
G&C - ES Integration	Expert systems for mission decisions	ADV DEV	USAF, DARPA, IRAD	✓
	Bingo			
	Emergency Mission related maneuvers			
	Lost communications/data link			
	Emergency Mission related events			
	Command Guidance (CG)	NONE	NONE	✓
	Collision Avoidance (CA)	NONE	NONE	
	Terrain Avoidance (TA)	NONE	NONE	

APPENDIX D ADVANCED TECHNOLOGY STATUS CHARTS

ADVANCED TECHNOLOGY STATUS TO SUPPORT THE AUTONOMOUS AIRCRAFT INITIATIVE PROGRAM (cont'd - 2)

Advanced Technology	Requirement	Development Status*	Further development planned by ----- **	Suggested for NASA development - to SIM - to flight
<u>Software Development</u>				
Software Development Environments	For airborne ES, airborne parallel processing, transputers	ADV DEV	USAF, DARPA, IRAD NASA	✓
<u>Navigation</u>				
Inertial Navigation	Low cost inertial components Automated ground map - INS update Automated NAV AID - INS update Automated GPS - INS update Automated Command Ship - INS transfer alignment & update	PRODUCT PRODUCT PRODUCT FLT DEMO FLT DEMO	IRAD NONE NONE NONE USAF	✓ ✓ ✓
<u>Airborne Computation</u>				
Airborne Computers	High throughput processors Parallel processors Multi processor - distributed architectures Fault tolerance/failure detection/reconfiguration	ADV DEV ADV DEV ADV DEV ADV DEV	ALL ALL ALL ALL	✓ ✓ ✓
<u>Communications</u>				
Data Link	High speed, medium range link	FLT DEMO	ALL	
Intermetting	Covert data transmission Unjammable data transmissions	FLT DEMO FLT DEMO	ALL ALL	

ADVANCED TECHNOLOGY STATUS TO SUPPORT THE
AUTONOMOUS AIRCRAFT INITIATIVE PROGRAM (cont'd - 3)

Advanced Technology	Requirement	Development Status*	Further development planned by ----- **	Suggested for NASA development - to SIM - to flight
<u>Sensors</u>				
RADAR	Low cost components	PRODUCT	ALL	
	Low maintenance/high reliability components	PRODUCT	ALL	
	Low weight/profile systems	PRODUCT	ALL	
FLIR	Low cost components	PRODUCT	ALL	
	Low maintenance/high reliability components	PRODUCT	ALL	
	Low weight/profile systems	PRODUCT	ALL	
	High resolution systems	PRODUCT	ALL	
Video including Electro-optical	Tracking algorithms/concepts	PRODUCT	USAF, USN, IRAD	
	Image Understanding	ADV DEV	ALL	
<u>Unmanned Airborne Vehicles</u>				
UAV Performance	Long range	PRODUCT	ALL	
	All weather operations	NONE	NONE	
	Recovery methods	NONE	NONE	
	High payload capability	PRODUCT	ALL	
UAV Reliability	High reliability	PRODUCT	ALL	
	Low maintenance	PRODUCT	ALL	
<u>Air Traffic Control</u>				
ARTC Integration	Voice command/response capability	NONE	NONE	✓
	Terminal Area Operations	NONE	NONE	✓
	Independent Operations capability	NONE	NONE	✓

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13. ABSTRACT (Maximum 200 words) This report describes the results of a consulting effort to aid NASA Ames-Dryden in defining a new initiative in aircraft automation. The initiative described herein is a multi-year, multi-center technology development and flight demonstration program. The initiative features the further development of technologies in aircraft automation already being pursued at multiple NASA centers and Department of Defense (DoD) research & development (R&D) facilities. The proposed initiative involves the development of technologies in intelligent systems, guidance, control, software development, airborne computing, navigation, communications, sensors, unmanned vehicles and air traffic control. It involves the integration and implementation of these technologies to the extent necessary to conduct selected and incremental flight demonstrations.					
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